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A General Reference Work on

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SEVEN VOLUMES

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Authors and Collaborators

FRANCIS B. CROCKER, E. M., Ph. D.

Professor of Electrical Engineering, Columbia University, New York
Past-President, American Institute of Electrical Engineers

❧

WILLIAM ESTY, S. B., M. A.

Head, Department of Electrical Engineering, Lehigh University
Joint Author of "The Elements of Electrical Engineering"

❧

HENRY H. NORRIS, M. E.

Formerly Professor of Electrical Engineering, Cornell University
Secretary, Society for the Promotion of Engineering Education
Chairman, Educational Committee, American Electric Railway Association

❧

GEORGE C. SHAAD, E. E.

Professor of Electrical Engineering, University of Kansas

❧

ROBERT ANDREWS MILLIKAN, Ph. D., Sc. D.

Professor of Physics, University of Chicago
Co-Author of "First Course in Physics"
Author of "Mechanics, Molecular Physics and Heat," and Co-Author of "Electricity, Sound and Light"
Member, American Physical Society

❧

KEMPSTER B. MILLER, M. E.

Consulting Engineer
Of the Firm of McMeen & Miller, Electrical Engineers, Chicago

❧

LOUIS DERR, S. B., A. M.

Professor of Physics, Massachusetts Institute of Technology

❧

CHARLES F. BURGESS, E. E.

Formerly Professor of Chemical Engineering and Applied Electrochemistry, University of Wisconsin
Past President, American Electrochemical Society
Member, American Institute of Electrical Engineers, American Chemical Society, Society of Chemical Industry, Western Society of Engineers
President, Northern Chemical Engineering Laboratories

Authors and Collaborators—Continued

MORTON ARENDT, E. E.

Assistant Professor of Electrical Engineering, Columbia University, New York
American Institute of Electrical Engineers

GEORGE W. PATTERSON, S. B., Ph. D.

Head, Department of Electrical Engineering, University of Michigan

WILLIAM H. FREEDMAN, C. E., E. E., M. S.

Head, Department of Electrical Engineering, University of Vermont
Formerly Head, Department of Applied Electricity, Pratt Institute

DANA PIERCE, B. A.

Electrical Engineer, Underwriters' Laboratories, Inc.

CHARLES G. ASHLEY

Electrical Engineer, and Expert in Wireless Telephony and Telegraphy

GEORGE S. MACOMBER, M. E.

Assistant Professor of Electrical Engineering, Cornell University
Formerly Instructor, Washington University
Formerly Engineer with Stromberg-Carlson Telephone Manufacturing Company

CHARLES E. KNOX, E. E.

Consulting Electrical Engineer
American Institute of Electrical Engineers

GEORGE W. CRAVENS

Mechanical and Electrical Engineer
Manager, Welding Apparatus Department, C. & C. Electric and Manufacturing Company, Garwood, New Jersey
Member, Association of Railway Electrical Engineers
American Institute of Electrical Engineers

EDWARD B. WAITE

Dean and Head, Consulting Department, American School of Correspondence
Formerly Research Assistant, Harvard College Observatory
American Society of Mechanical Engineers
Western Society of Engineers

C. C. ADAMS, B. S.

Switchboard Engineer with General Electric Company

Authors and Collaborators—Continued

HUGO DIEMER, M. E.

Professor of Industrial Engineering, Pennsylvania State College
American Society of Mechanical Engineers

* * *

O. J. BUSHNELL

Superintendent, Meter Department, Commonwealth Edison Company

* * *

LAWRENCE K. SAGER, S. B., M. P. L.

Patent Attorney and Electrical Expert, New York City

* * *

JOHN H. JALLINGS

Mechanical Engineer
For Twenty Years Superintendent and Chief Constructor for J. W. Reedy Elevator Co.

* * *

DAVID P. MORETON, B. S., E. E.

Associate Professor of Electrical Engineering, Armour Institute of Technology
American Institute of Electrical Engineers

* * *

GLENN M. HOBBS, Ph. D.

Secretary and Educational Director, American School of Correspondence
Formerly Instructor in Physics, University of Chicago
American Physical Society

* * *

GEORGE R. METCALFE, M. E.

Editor, American Institute of Electrical Engineers
Formerly Head, Technical Publication Department, Westinghouse Electric & Manufacturing Company

* * *

A. G. TURNBULL

Meter Department, Commonwealth Edison Company

* * *

J. P. SCHROETER

Consulting Engineer, Department of Electrical Engineering, American School of Correspondence

* * *

CHAS. THOM

Chief, Quadruplex Department, Western Union Main Office, New York City

* * *

JESSIE M. SHEPHERD, A. B.

Head, Publication Department, American School of Correspondence

Authorities Consulted

THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes.* They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known works should be in the library of every electrician and engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

FRANCIS B. CROCKER, E. M., Ph. D.

Professor of Electrical Engineering, Columbia University; Past-President, American Institute of Electrical Engineers
Author of "Electric Lighting"; Joint Author of "Management of Electrical Machinery," "Electric Motors"

◆

SCHUYLER S. WHEELER, D. Sc.

President, Crocker-Wheeler Company; Past-President, American Institute of Electrical Engineers
Joint Author of "Management of Electrical Machinery"

◆

ALFRED E. WIENER, E. E., M. E.

Member, American Institute of Electrical Engineers
Author of "Practical Calculation of Dynamo-Electric Machines"

◆

WILLIAM S. FRANKLIN, M. S., D. Sc.

Professor of Physics, Lehigh University
Joint Author of "The Elements of Electrical Engineering," "The Elements of Alternating Currents"

◆

WILLIAM ESTY, S. B., M. A.

Head of Department of Electrical Engineering, Lehigh University
Joint Author of "The Elements of Electrical Engineering"

◆

R. B. WILLIAMSON

Joint Author of "The Elements of Alternating Currents"

◆

HORATIO A. FOSTER

Consulting Engineer; Member of American Institute of Electrical Engineers; Member of American Society of Mechanical Engineers
Author of "Electrical Engineer's Pocket-Book"

---

*An extended list of books on Electrical Engineering may be found in Volume VII of this Cyclopedia.

Authorities Consulted—Continued

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, Massachusetts Institute of Technology; Member, American Society of Mechanical Engineers, American Institute of Electrical Engineers, etc.
Author of "A Textbook on Electromagnetism and the Construction of Dynamos"; Joint Author of "Alternating Currents and Alternating-Current Machinery"

◆

J. FISHER-HINNEN

Late Chief of the Drawing Department at the Oerlikon Works
Author of "Continuous-Current Dynamos"

◆

WILLIAM L. HOOPER, Ph. D.

Head of Department of Electrical Engineering, Tufts College
Joint Author of "Electrical Problems for Engineering Students"

◆

ROBERT ANDREWS MILLIKAN, Ph. D.

Professor of Physics, University of Chicago
Joint Author of "A First Course in Physics," "Electricity, Sound and Light," etc.

◆

JOHN PRICE JACKSON, M. E.

Professor of Electrical Engineering, Pennsylvania State College; Member, American Institute of Electrical Engineers, etc.
Joint Author of "Alternating Currents and Alternating-Current Machinery"

◆

MICHAEL IDVORSKY PUPIN, A. B., Sc. D., Ph. D.

Professor of Electro-Mechanics, Columbia University, New York
Author of "Propagation of Long Electric Waves," and "Wave-Transmission Over Non-Uniform Cables and Long-Distance Air Lines"

◆

LAMAR LYNDON, B. E., M. E.

Consulting Electrical Engineer; Associate Member of American Institute of Electrical Engineers; Member, American Electrochemical Society
Author of "Storage Battery Engineering"

◆

EDWIN J. HOUSTON, Ph. D.

Professor of Physics, Franklin Institute, Pennsylvania; Joint Inventor of Thomson-Houston System of Arc Lighting; Electrical Expert and Consulting Engineer
Joint Author of "Alternating Currents," "Arc Lighting," "Electric Heating," "Electric Motors," "Electric Railways," "Incandescent Lighting," etc.

◆

ARTHUR E. KENNELY, D. Sc.

Professor of Electrical Engineering, Harvard University
Joint Author of "Alternating Currents," "Arc Lighting," "Electric Heating," "Electric Motors," "Electric Railways," "Incandescent Lighting," etc.

Authorities Consulted—Continued

SILVANUS P. THOMPSON, D. Sc., B. A., F. R. S., F. R. A. S.

Principal and Professor of Physics in the City and Guilds of London Technical College; Past-President, Institution of Electrical Engineers
Author of "Electricity and Magnetism," "Dynamo-Electric Machinery," "Polyphase Electric Currents and Alternate-Current Motors," "The Electromagnet," etc.

◆

KEMPSTER B. MILLER, M. E.

Consulting Engineer of the Firm of McMeen and Miller, Electrical Engineers, Chicago
Author of "American Telephone Practice"; Joint Author of "Telephony"

◆

MAURICE A. OUDIN, M. S.

Member, American Institute of Electrical Engineers
Author of "Standard Polyphase Apparatus and Systems"

◆

FREDERICK BEDELL, Ph. D.

Professor of Applied Electricity, Cornell University
Author of "The Principles of the Transformer"; Joint Author of "Alternating Currents"

◆

H. F. PARSHALL

Member of American Institute of Electrical Engineers, Institution of Electrical Engineers, American Society of Mechanical Engineers, etc.
Joint Author of "Armature Windings of Electric Machines"

◆

J. A. FLEMING, M. A., D. Sc. (London), F. R. S.

Professor of Electrical Engineering in University College, London; Late Fellow and Scholar of St. John's College, Cambridge; Fellow of University College, London; Member, Institution of Electrical Engineers; Member of the Physical Society of London; Member of the Royal Institution of Great Britain, etc.
Author of "The Alternate-Current Transformer," etc.

◆

LOUIS BELL, Ph. D.

Consulting Electrical Engineer; Lecturer on Power Transmission, Massachusetts Institute of Technology
Author of "Electric Power Transmission," "Power Distribution for Electric Railways," "The Art of Illumination," "Wireless Telephony," etc.

◆

CHARLES PROTEUS STEINMETZ

Consulting Engineer, with the General Electric Company; Professor of Electrical Engineering, Union College
Author of "The Theory and Calculation of Alternating-Current Phenomena," "Theoretical Elements of Electrical Engineering," etc.

◆

CYRILL M. JANSKY, B. S., B. A.

Associate Professor of Electrical Engineering, University of Wisconsin
Author of "Electric Meters"

Authorities Consulted—Continued

J. J. THOMSON, D. Sc., LL. D., Ph. D., F. R. S.

Fellow of Trinity College, Cambridge University; Cavendish Professor of Experimental Physics, Cambridge University
Author of "The Conduction of Electricity Through Gases," "Electricity and Matter," etc.

❧

HENRY SMITH CARHART, A. M., LL. D.

Professor Emeritus of Physics, University of Michigan
Author of "Primary Batteries," "Elements of Physics," "University Physics," "Electrical Measurements," "High School Physics," etc.

❧

F. A. C. PERRINE, A. M., D. Sc.

Consulting Engineer; Formerly President, Stanley Electric Manufacturing Company; Formerly Manager, Insulated Wire Department, John A. Roebling's Sons Company
Author of "Conductors for Electrical Distribution"

❧

WILLIAM MAVER, Jr.

Ex-Electrician, Baltimore & Ohio Telegraph Company
Author of "Wireless Telegraphy," "American Telegraphy and Encyclopedia of the Telegraph"

❧

E. B. RAYMOND

Testing Department, General Electric Company
Author of "Alternating-Current Engineering"

❧

AUGUSTUS TREADWELL, Jr., E. E.

Associate Member, American Institute of Electrical Engineers
Author of "The Storage Battery: A Practical Treatise on the Construction, Theory, and Use of Secondary Batteries"

❧

SAMUEL SHELDON, A. M., Ph. D.

Professor of Physics and Electrical Engineering, Polytechnic Institute of Brooklyn
Joint Author of "Dynamo-Electric Machinery," "Alternating-Current Machines"

❧

HOBART MASON, B. S., E. E.

Assistant in Electrical Engineering, Polytechnic Institute of Brooklyn; Associate Member, American Institute of Electrical Engineers
Joint Author of "Dynamo-Electric Machinery," "Alternating-Current Machines"

❧

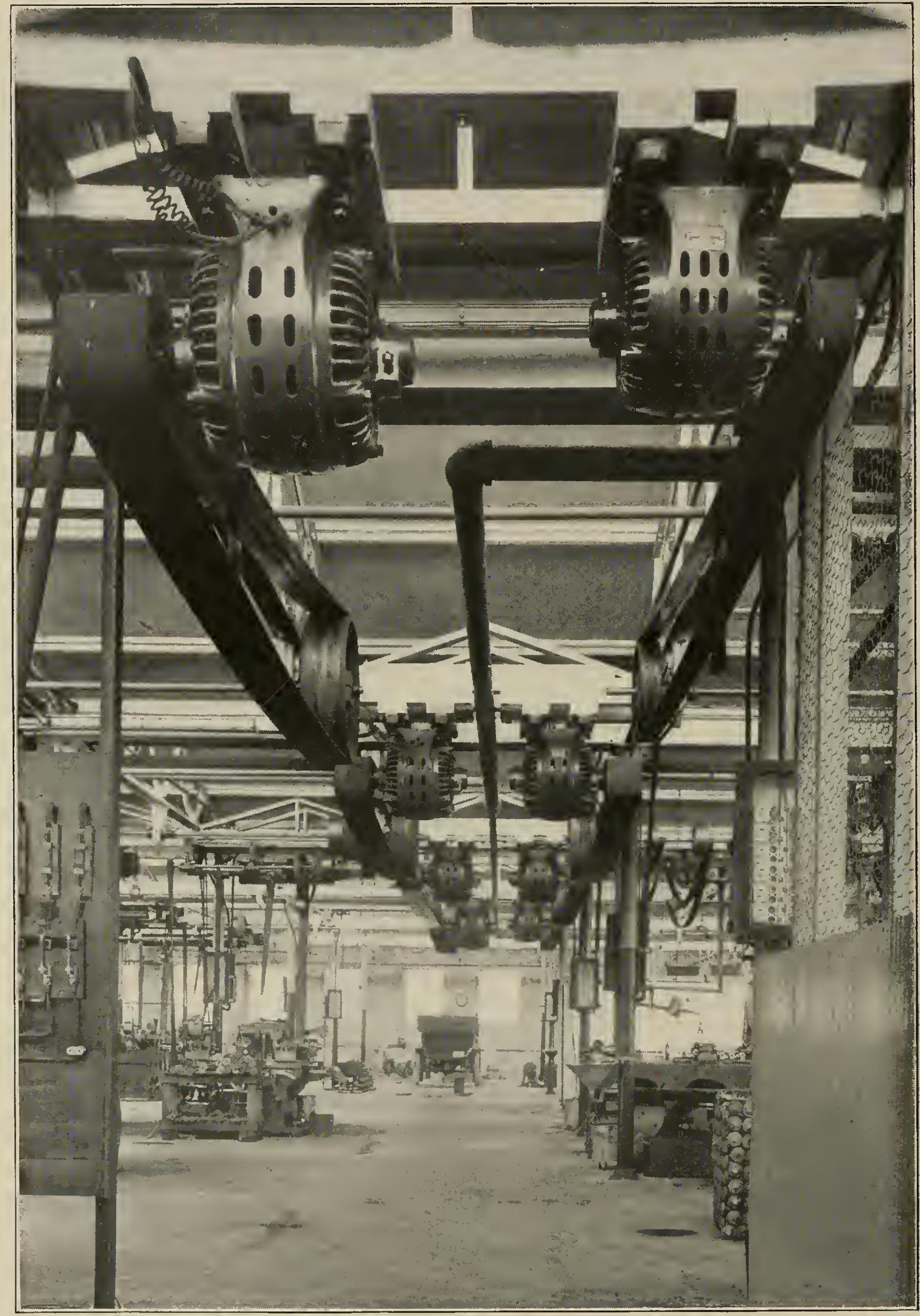
H. M. HOBART, B. Sc.

Member, Institution of Civil Engineers, American Institute of Electrical Engineers
Joint Author of "Armature Construction"

❧

ALBERT CUSHING CREHORE, A. B., Ph. D.

Electrical Engineer; Assistant Professor of Physics, Dartmouth College
Author of "Synchronous and Other Multiple Telegraphs"; Joint Author of "Alternating Currents"



INSTALLATION SHOWING GROUP DRIVE FOR MUSKEGAN MOTOR SPECIALTIES COMPANY. FAIRBANKS-MORSE INDUCTION MOTORS USED

Courtesy of Fairbanks, Morse and Company

Foreword

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted — and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat, and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome this difficulty the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors into a logical and unified whole.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power.

It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used wherever they may be helpful in explaining the subject under discussion.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation has been found to be the best devised for the education of the busy, practical man.

¶ A glossary of the electrical terms used in this Cyclopedia will be found in Volume VII. The definitions are given in simple language and, where it was thought desirable, reference has been made to the volume and page where the reader may find added matter on the topic sought.

¶ Attention is directed to a bibliography of the best literature in Electrical Engineering, in Volume VII. No attempt has been made to exhaust the sources but merely to provide the names, authors, and publishers of books which would appeal to the widest circle of readers.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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* For page numbers, see foot of pages.

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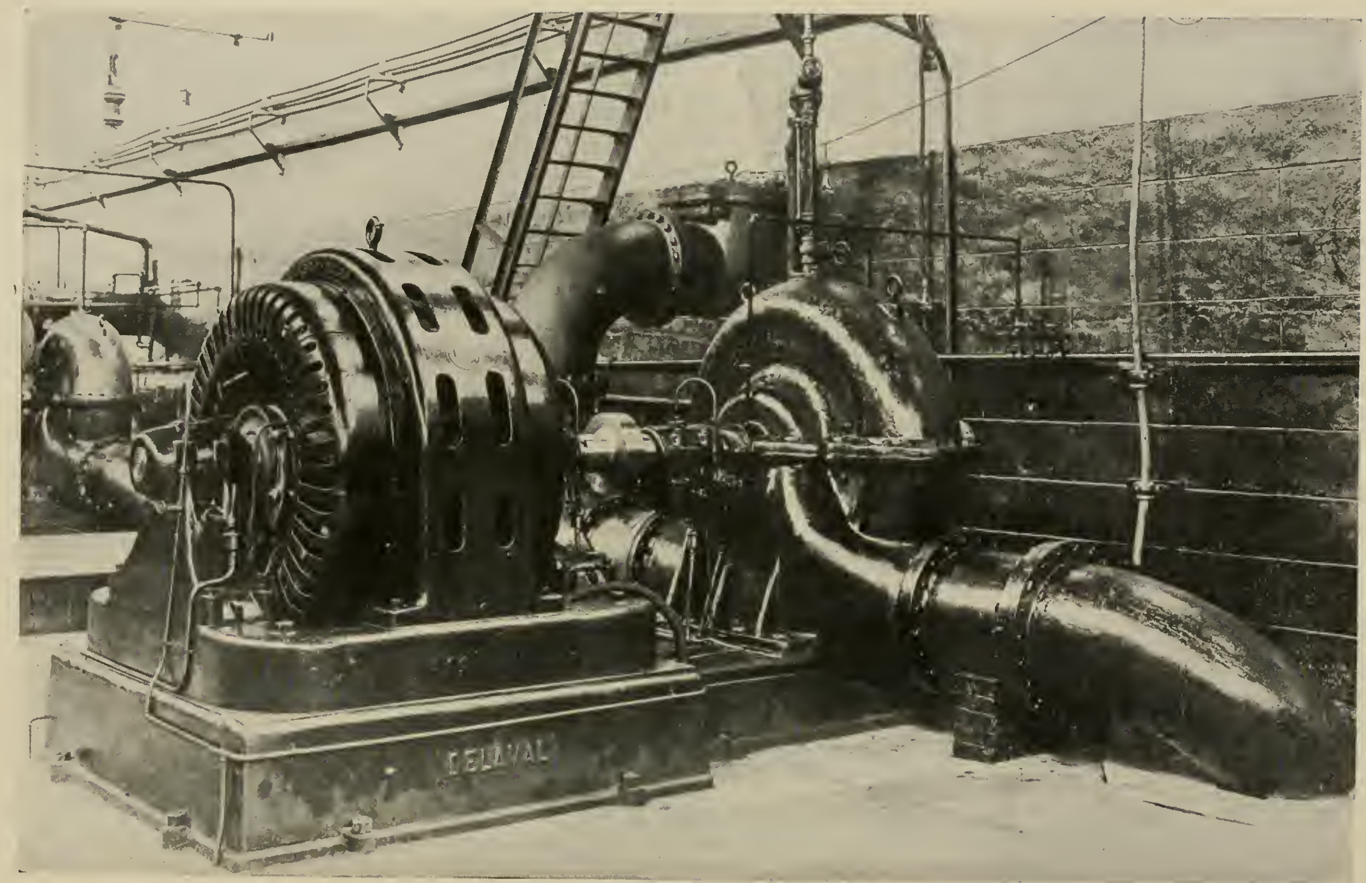

500 H. P. 6600-VOLT SYNCHRONOUS MOTOR, DRIVING DE LAVAL TURBINE PUMP
Courtesy of Crocker-Wheeler Company

DIRECT-CURRENT MOTORS

Comparison between Dynamos and Motors. The dynamo is a machine for the conversion of mechanical into electrical energy; conversely, the electric motor converts electrical energy into mechanical work. The electrical energy delivered by the dynamo must be obtained from a steam engine, water-wheel, or other power; and the mechanical power obtained from the electric motor comes from the energy of the current flowing through its armature. The two machines are exactly complementary; and, in the case of direct-current apparatus, we shall see that the same structure can be used for either service. The differences that are found in practice are largely mechanical, and arise chiefly from the conditions under which the motor must work.

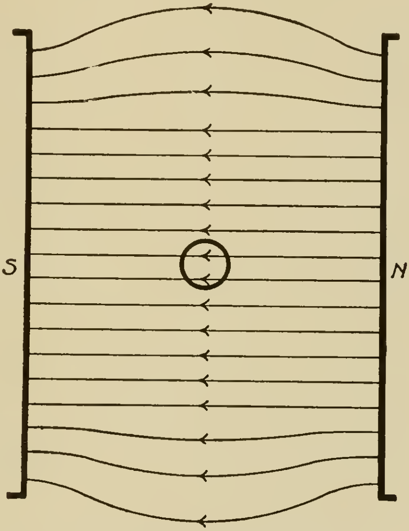

Fig. 1. Conductor Carrying No Current, in a Magnetic Field.

The study of the electric motor, therefore, begins with a knowledge of the dynamo; and before reading the following pages, the student should be sure that he understands fully the fundamental principles and mechanical details of Dynamo-Electric Machinery.

Force on a Conductor Carrying a Current. Fig. 1 represents a wire lying in a magnetic field, and carrying no current. If the polar surfaces of the field are large and close together, the magnetic lines pass straight from one to the other; they are not distorted, whether the wire is at rest or in motion. This is the condition in the air-gap of a dynamo or motor when no current is flowing in the armature conductors. The rotation of the armature in the magnetic field generates an electromotive force, but there is no mechanical force upon the conductors due to this action in itself. When, however, a current flows, it sets up a magnetic field of its own about the conductor, as shown in Fig. 2; and this field distorts the original field in which the conductor lies, making the magnetic lines denser on one side and less dense on the other. This is shown in Fig. 3.

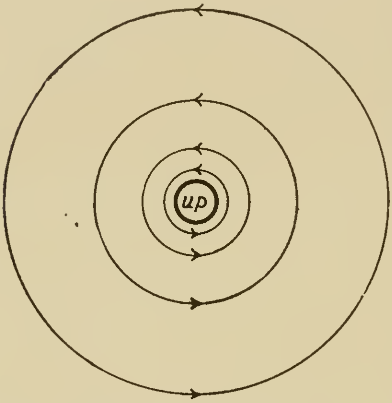

Fig. 2. Magnetic Field about a Conductor Carrying a Current.

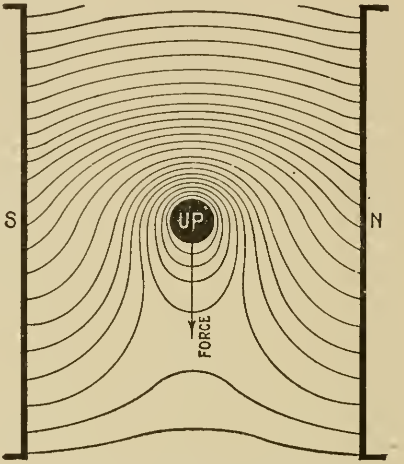

Fig. 3. Magnetic Field around Conductor in Dynamo or Motor Air-Gap.

Since the magnetic lines of a field endeavor to straighten and shorten themselves, the result of this distribution is a force upon the wire, pushing it in the direction of the arrow; and this is the principle of the electric motor. As in the dynamo, there are required: (1) a magnetic field; (2) a conductor lying perpendicular to it; and (3) provision for motion of the conductor across the field, in a direction perpendicular both to itself and to the field.

Fleming's Rule. The relation between the directions of the force, current, and magnetic lines can be most easily remembered by what is known as *Fleming's Rule.* Extend the forefinger, middle finger, and thumb, at right angles to one another; for example, the forefinger directly forward, the middle finger sideways, and the thumb upwards. Then if the forefinger represents the direction of the magnetic lines (that is, from the N pole through the air to the S pole), the middle finger will represent the direction of the current, and the thumb the direction of the motion. The right hand is to be used for the case of the dynamo, the left hand for the case of the motor.

Barlow's Wheel. An illustration of this principle is found in the simple electric motor invented by Peter Barlow in 1823, and illustrated in Fig. 4. A star-shaped metal wheel, usually of copper, rotates with its lowest points dipping into a little insulated pool of mercury. The wheel is connected through its bearings with one pole of a battery, the mercury to the other pole, the current flowing radially upward or downward through the wheel. When a horseshoe magnet is brought over the wheel, so that the portion carrying the current lies between the magnet-poles, the wheel revolves briskly, the direction of rotation changing whenever the direction of the current or the magnetic field is reversed.

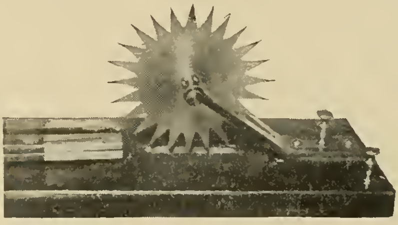
Fig. 4. Barlow's Wheel.

Magnitude of the Force on a Wire Carrying a Current. If the magnetic field has one line of force per square centimeter, and one absolute electromagnetic unit of current (10 amperes) is flowing in the conductor, the force upon each linear centimeter of the conductor will be one dyne. Hence, since the effects are directly proportional to the quantities involved, a wire L centimeters long, lying across a field of B lines per square centimeter, and carrying a current of I amperes, will be subjected to a force of:

$$L\ B\ \frac{I}{10} \text{ dynes.}$$

This is practically a corollary of the definition of the ampere in electromagnetic measure.*

This expression may be reduced to the inch and pound units which are more common in American shop practice, by noting that one inch equals 2.54 centimeters; that one dyne is $\frac{1}{981}$ of the weight of a gram, nearly; and that 453.59 grams, or nearly 445,000 dynes, equal the weight of one pound. Hence the force F' upon

---

*Consult S. P. Thompson's *Elementary Lessons in Electricity and Magnetism*, or any similar textbook on Electricity.

a wire L'' inches long, lying perpendicularly across a field of B'' lines per square inch, and carrying a current of I amperes, will be:

$$2.54\,L'' \times \frac{B''}{(2.54)^2} \times \frac{I}{10} \text{ dynes};$$

or,

$$F' = \frac{L''\,B''\,I}{2.54 \times 445{,}000 \times 10} = \frac{L''\,B''\,I}{11{,}303{,}000} \text{ pounds, approximately.}$$

Upon N similar wires, the force will be N times as great.

Example. Fourteen hundred conductors of a certain large armature, each 11 inches long, lie in magnetic fields of 42,000 lines per square inch. What is the total drag upon them when each carries a current of 60 amperes?

Solution. The force is:

$$\frac{1{,}400 \times 11 \times 42{,}000 \times 60}{11{,}303{,}000} = 3433 \text{ pounds, nearly.}$$

EXAMPLE FOR PRACTICE

Under the poles of a certain 25-kilowatt machine, there are 225 conductors, each $6\frac{1}{2}$ inches long, in magnetic fields of 40,000 lines per square inch. What current must flow in each conductor in order to give a total rotative force of 200 pounds?

Ans. 38.64 amperes, nearly.

In considering questions like the above, it is important to observe that only the conductors lying beneath the poles are subjected to these forces; and that the current in the individual conductors is not the full current of the machine, but only a fraction of it—one-half in the case of bipolar and wave-wound armatures; and one-fourth, one-sixth, or less, in the case of lap-wound armatures, according as the machine has four, six, or more poles.

It will now be clear that the driving force upon a dynamo armature must be increased in direct proportion to the load put upon the machine, and that the force causing a motor armature to rotate also depends on the current in it. The dynamo current is determined by Ohm's law, and the engine or water-wheel governor takes care of the power supply; but the way in which the electric motor adapts itself to the variations in its work, taking always just the necessary current for the work in hand, is not so clear at first sight. The explanation involves a most important property of the machine, known as the *counter-electromotive force.*

Counter-E.M.F. of a Motor. Since the armature wires rotate in magnetic fields, exactly as in the case of the dynamo, all the conditions for the generation of E.M.F. are fulfilled; and we should expect the motor armature to generate an E.M.F. accordingly, while in motion. The existence of such an E.M.F., and its direction, may be shown by the following experiment:

Take a small shunt-wound motor, and connect it as for ordinary running, but with the addition of a suitable incandescent lamp *L* and an ammeter *A* across the armature terminals, as shown in Fig. 5. When the motor is running, the lamp will glow, obviously supplied from the line; and the ammeter will show the direction of the current through it, as indicated by the arrow at *L*. The dotted arrows show the direction of the current in the other parts of the circuit. Now let the double-pole switch be opened; so far as the electrical conditions are concerned, the circuits may then be represented by Fig. 6; and the machine will run for a little while as a dynamo, driven by the energy stored in the rotating armature. The lamp still glows, and the ammeter shows that the current through it is in the original direction, dying out as the armature slows down to rest. Since the source of E.M.F. in the system is the revolving armature, and the direction of the current through the ammeter is known, it follows that in the other parts of the circuit the current must flow as indicated by the dotted arrows in Fig. 6. The reversal of the current in the armature can be shown directly by putting a second ammeter into the armature circuit, as indicated at *B*, Fig. 6, but the experiment can be performed equally well without it.

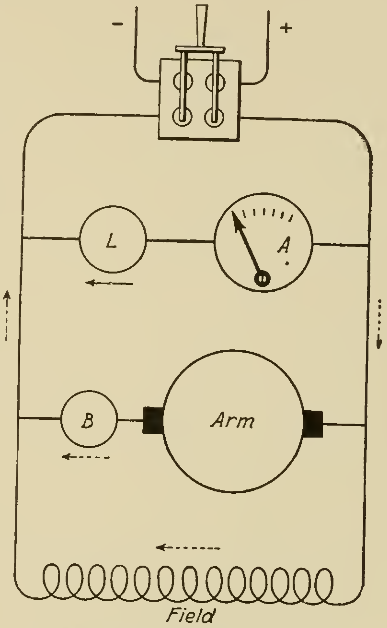

Fig. 5. Motor Connections to Show Counter-E.M.F.

This experiment is very instructive if performed with a motor of several horse-power. The experimenter should prevent the arm of the starting rheostat from flying back until the armature has entirely ceased to revolve.

A comparison of Figs. 5 and 6 now brings the conclusion that the direction of the current in the various parts of the circuit must be due to the existence of an E.M.F. in the revolving motor armature which is opposite in direction to the line E.M.F., and hence opposes the flow of current through the armature. For this reason it is called the *counter-E.M.F.* The electrical difference, therefore, between a dynamo and a motor is that in the dynamo the current flows *with* the E.M.F. of the armature, while in the motor it flows *against* it.

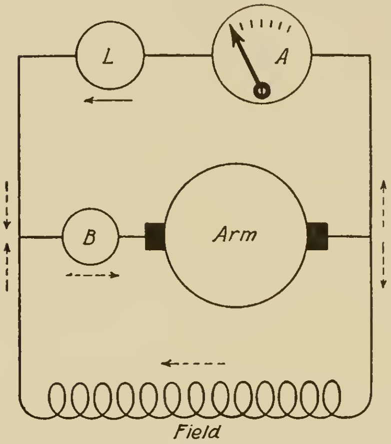

Fig. 6. Currents in Motor Circuits after Opening Main Switch.

Fundamental Motor Equation. From the above it follows that the current through the revolving motor armature is always less than the value obtained by simple calculation from Ohm's law, because E, the line E.M.F., is partially neutralized by e, the opposing counter-E.M.F. Hence the fundamental motor equation may be written:

$$I = \frac{E-e}{R}, \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

in which I represents the current through the armature, and R the resistance of the armature circuit—armature, brush gear, and any other resistance that may be present.

The counter-E.M.F. is not readily measured; it is best calculated from Equation 1 with a knowledge of the other three quantities, which are easily measurable.

Example. A certain motor armature with its brush gear has a resistance of 0.188 ohm; and when running at a certain speed, takes a current of 55 amperes from a 220-volt line. What counter-E. M. F. is developed under these conditions?

Solution. Substituting the given values in Equation 1, we have:

$$55 = \frac{220 - e}{0.188};$$

whence,

$$e = 209.66 \text{ volts.}$$

EXAMPLE FOR PRACTICE

What current will flow through the above armature when its counter-E.M.F. is nine-tenths of the line voltage?

ANS. 117 amperes, nearly.

From these considerations it is plain that in the absence of other resistance in the armature circuit than that of the armature itself, a slight change in the counter-E.M.F. may make a great difference in the strength of the current flowing. Further, since the figures are taken from actual machines, it is to be noted that under ordinary running conditions the counter-E.M.F. rises well up toward the value of the line E.M.F. It can of course never quite equal the line E.M.F., for in that case no current would flow; and even when running without load, the friction and electrical losses of the motor absorb some power, so that a small fraction of the full-load current will flow, though the armature delivers no power at the pulley.

Efficiency and Losses. The energy-losses of the motor are the same as those of the dynamo, and may be classified under two heads:

Electrical Losses:
(*a*) I^2R losses in armature conductors and brush gear.
(*b*) I^2R losses in field windings.
Stray-Power Losses:
(*c*) Friction: of bearings, brushes, and air-currents.
(*d*) Iron losses: eddy currents in armature core, teeth, and magnet-poles; hysteresis in armature core and teeth.
(*e*) Commutator losses: wasteful currents in coils during commutation.
(*f*) Eddy currents in armature conductors.

The electrical losses (*a*) and (*b*) are measurable without much trouble; the others are very difficult to obtain separately, and are usually taken together under the general name *stray power*. For shunt motors, the field I^2R loss is independent of the load; the armature I^2R, of course, varies with the load. In the series motor, both field and armature I^2R vary with the load, since the same current passes through both. The stray-power loss is nearly constant for ordinary operating conditions, though it increases slightly with the speed of the armature.

The commercial efficiency η of a motor is simply the fraction of the power supplied that is available at the shaft; that is, it is the ratio of the power delivered to the power supplied; or, in the form of an equation:

$$\eta = \text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}}. \quad . \; . \; . \; (2)$$

The following table shows average values for the commercial efficiency of ordinary motors of various sizes, at full load:

TABLE I

Commercial Efficiency of Ordinary Motors

Full Load H.P.	Efficiency (Per Cent)
0.02 (Fans)	30
0.05 "	42
0.1	50
0.5	63
1.	70
5.	82
10.	85
25.	88
50.	89.5
100.	91
200.	92.5

The low figures for small motors are caused by disproportionately large field I^2R and friction losses.

Variation of Efficiency with Load. The efficiency varies with the load, because some of the losses are constant and some variable, the chief variable being the armature I^2R. When the motor is running idle, the current is small, and all its energy goes to supply the losses, the commercial efficiency being therefore zero. As the motor is loaded, the output at first increases faster than the losses, and the efficiency rises rapidly, reaching a maximum at a certain load which depends on the design of the machine. When the load is very heavy, the great increase in the armature I^2R causes the efficiency to fall again.

The efficiency is a maximum when the constant and variable losses are equal—for example, in the case of a shunt motor, when the armature I^2R loss equals the sum of the stray-power and field I^2R losses.* Since the distribution of the losses may be controlled by

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* This proposition may be proved by algebraic methods, as follows:

Denoting by S the sum of the field I^2R loss and the stray power, the efficiency may be written:

$$\eta = \text{Efficiency} = \frac{EI - I^2R - S}{EI} = 1 - \left(\frac{IR}{E} + \frac{S}{EI}\right).$$

the designer within fairly wide limits, it follows that a motor (or a dynamo) may be designed to show its maximum efficiency at any specified fraction of its full load, or even at overload, though the latter is unusual. Motors should be designed to have their maximum efficiency with the load at which they are most used. An ordinary shop motor should show a maximum at about 75 per cent of its full rated load; a street-railway motor, at about two-thirds of the maximum power it is expected to develop (see Fig. 33); a fan motor, at its full load; and so on. A motor with large constant losses and small variable losses will have a low efficiency at light loads, and a high one at full load; while a machine with small constant and large variable losses will have a much higher efficiency at light loads than at full load. The most important point is not the full-load efficiency, but rather the maximum efficiency, coupled with another figure which we may call the *all-day efficiency.*

All-Day Efficiency. This is a matter of some importance in practice. It is simply the ratio between the work obtained from the motor during the day, and the energy taken from the line in the same time.

The difference between the performances of different machines in this respect, is best shown by an example. Suppose we have two 100-horse-power motors, motor A having constant losses of 2,700 watts, and armature I^2R losses of 6,400 watts; and motor B having constant losses of 4,800 watts, and armature I^2R losses of 3,200 watts. Suppose them to run through a 9-hour day, and that

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For maximum efficiency, it is plain that $\frac{IR}{E} + \frac{S}{EI}$ must be a minimum; or, since E is a constant, that $IR + \frac{S}{I}$ must be a minimum. The sum of these two terms will be large when I is either very large or very small, and the problem is to determine the particular value of I for which it will be smallest. Denoting the sum by k, we may write:

$$IR + \frac{S}{I} = k, \quad \ldots\ldots\ldots\ldots \quad \text{(a)}$$

which is a quadratic equation in I. Solving this by ordinary algebra gives:

$$I = \frac{k}{2R} + \frac{1}{2R}\sqrt{k^2 - 4\,RS} \quad \ldots\ldots\ldots \quad \text{(b)}$$

Now, since a negative quantity cannot have a square root, the quantity under the radical sign cannot be less than zero, and therefore the smallest value k can have will be determined from the equation;

$$k^2 - 4\,RS = 0. \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(c)}$$

Inserting in (a) the value of k obtained from (c), and reducing, gives as the final result $I^2R = S$; or, in other words, when a motor is working at its highest efficiency, the armature current is such as to make the variable losses just equal to the constant losses.

they run for 2 hours at quarter-load, 4 hours at half-load, and 3 hours fully loaded; let us calculate the energy actually delivered, and the energy taken from the line. Remembering that 1 H.P. = 746 watts, and that the I^2R loss varies as the square of the current, we have, for motor *A*, the following:

Constant Losses:	2,700 watts for 9 hours,	24,300	watt-hours.
I^2R Losses:	$\frac{1}{16}$ of 6,400 watts for 2 hours,	800	"
	$\frac{1}{4}$ of 6,400 watts for 4 hours,	6,400	"
	6,400 watts for 3 hours,	19,200	"
Output:	$\frac{1}{4}$ of 74,600 watts for 2 hours,	37,300	"
	$\frac{1}{2}$ of 74,600 watts for 4 hours,	149,200	"
	74,600 watts for 3 hours	223,800	"
Input for the day:		461,000	watt-hours.

The all-day efficiency is therefore:

$$\frac{\text{Output}}{\text{Input}} = \frac{410,300}{461,000} = 89 \text{ per cent}$$

For motor *B*, we have:

Constant Losses:	4,800 watts for 9 hours,	43,200	watt-hours.
I^2R Losses:	$\frac{1}{16}$ of 3,200 watts for 2 hours,	400	"
	$\frac{1}{4}$ of 3,200 watts for 4 hours,	3,200	"
	3,200 watts for 3 hours,	9,600	"
Output:	as for motor *A*,	410,300	"
Input for the day:		466,700	watt-hours.

Hence the all-day efficiency is:

$$\frac{410,300}{466,700} = 87.9 \text{ per cent.}$$

Thus, although motor *B* has a higher full-load efficiency than motor *A* (90.3 per cent as compared with 89.1 per cent), the latter returns the larger percentage of the energy put into it during the day, the difference being 5,700 watt-hours, or 5.7 kilowatt-hours in favor of *A*. It is thus seen to be a matter of some importance to keep the constant losses down to the lowest point consistent with satisfactory operation in other respects; and machines should be selected by the purchaser with reference to this point, as well as for full-load efficiency. For this reason the efficiency values at different loads may vary several per cent in motors of different but equally good design; and the figures in the preceding efficiency table must be regarded as only approximate. Most shop and factory motors are subjected to very variable loads; and the average load of a large number of motors in a given plant will often be found to be considerably less than 25 per cent of the total rated capacity of the motors in circuit. With motors designed upon the lines mentioned above, it may be said that the saving at average day loads would range from 4 per cent to 10 per cent in the larger motors (from 60 to 120 horsepower), up to a saving of 8 per cent to 15 per cent in the smaller motors.*

EXAMPLE FOR PRACTICE

Suppose a 100-horse-power motor were designed so as to have constant losses of 6,400 watts and armature I^2R losses of 2,700 watts, and that it works under the same conditions as those given for motor *A* in the preceding example. What would its all-day efficiency be, and how much more energy would it take from the lines in one day than motor *A*? Ans. 85.7 per cent; 18 + kilowatt-hours.

Current Required by Motors. The value of the full-load current is usually stamped upon the name-plate of the machine. If not, it can be approximately found from the rated output by assuming a value for the efficiency.

Example. What current will be required by a 220-volt, 15-horse-power motor?

Solution. From Table I (p. 8), the efficiency may be taken as 86 per cent. The output is:

$$15 \times 746 = 11{,}190 \text{ watts.}$$

The input is:

$$\frac{11{,}190}{0.86} = 13{,}012 \text{ watts.}$$

The current is therefore:

$$\frac{13{,}012 \text{ watts}}{220 \text{ volts}} = 59.1 \text{ amperes.}$$

EXAMPLES FOR PRACTICE

1. A 50-horse-power motor is connected to a 500-volt line which will carry 60 amperes. Can the motor be operated at full load? Ans. No.

2. Assuming an efficiency of 88 per cent, what is the maximum power that can be obtained from the above motor without overloading the line? Ans. 35.4 horse-power, nearly.

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*Hobart, *Electric Motors*, 1904.

Effect of Counter-E.M.F. on Efficiency. At first sight it might appear that the counter-E.M.F. is merely an incident of operation, or at least a hindrance to the best performance of the machine; but a more careful study of the question shows that it is an essential factor in the economy of the motor. This can be most clearly shown by taking the artificially simple case of a motor whose only losses are the armature I^2R. This would be very nearly realized by a frictionless magneto-motor. Its efficiency η would be:

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{EI - I^2R}{EI} = \frac{E - IR}{E}. \quad \ldots (3)$$

But,

$$I = \frac{E - e}{R};$$

whence,

$$IR = E - e.$$

Substituting this value of IR in Equation 3, we have:

$$\eta = \frac{E - (E - e)}{E} = \frac{e}{E}. \quad \ldots\ldots\ldots (4)$$

That is, the efficiency is directly proportional to the counter-E.M.F.

This proposition is known as *Siemens' Law of Efficiency.* It should not be understood as implying anything concerning the output. The current taken by the motor diminishes as the counter-E.M.F. rises; and the power delivered also diminishes as the armature approaches full speed. But the equation does mean that the power delivered per ampere taken from the line is greater as the value of e approaches E; and therefore, though the actual power delivered is less, the available *percentage* of the line energy is greater than if the actual output were larger. For this reason it is entirely possible to operate a motor beyond its rated capacity, though at a reduced efficiency, the permissible amount and duration of the overload depending chiefly on the time required for the increased losses to heat up the machine dangerously.

In the actual motor, where other losses enter, the case is not quite so simple and direct as the above; but the difference is small, the complete equation being:

$$\eta = \frac{e - \frac{S}{I}}{E},$$

in which S is the sum of the field I^2R and the stray power, as on page 8. The fraction $\frac{S}{I}$ is only a few per cent of E, in ordinary running under load, so that the Siemens law holds, except for small values of I—that is, for light loads.

So it follows that the counter-E.M.F. is a valuable property of the motor, to be cultivated rather than ignored or eliminated; and the lack of success of early types of motors was in part due to a failure to realize this. In other words, the motor should be designed and operated to generate an E.M.F. exactly like a dynamo; and the formula for efficiency shows that the electrical and mechanical losses should be kept as small as practicable. The requirements for dynamos and motors are therefore the same, and it should now be clear that they must be designed along the same electrical lines. Consequently they are interchangeable.

The fact that a dynamo will transmit power to a similar machine as a motor is said to have been brought to light by a Paris workman in 1873, who accidentally connected the wires of an idle dynamo to the terminals of one in operation, whereupon the motionless armature immediately started up at full speed. The discovery of the general principle of interchangeability, however, dates back to 1852, and perhaps earlier.*

Torque. The torque of a motor is the turning moment or twist exerted upon the shaft. Grasp the pulley of a small motor firmly in the hand, and close the switch; a strong twisting action will be felt, which will set the armature in rapid rotation when freed. With the armature stationary, the torque is sometimes called *static torque*, to distinguish it from the *running torque* of the rotating armature, available at the pulley; the latter is less than the former by the amount necessary to overcome armature friction and core losses.

Since torque is caused by a force acting at the end of a lever arm, it is measured by the product of the force and the length of the arm—for example, by the product of the working pull of the belt and the radius of the pulley; or by the force upon the armature wires, multiplied by their average distance from the axis of the shaft. This product is generally expressed in *pound-feet*, which term denotes the

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*S. P. Thompson, *Dynamo-Electric Machinery*, Edition of 1888, p. 13.

pull in pounds multiplied by the length of the lever arm in feet.* Thus a torque of 60 pound-feet may represent a working belt-pull of 60 pounds on a pulley 1 foot in radius, or a pull of 72 pounds on a pulley whose diameter is 20 inches, or any other combination of force and arm whose product is 60 pound-feet. For simplicity, torque is sometimes expressed in pounds only, a radius of one foot being understood or implied; but this is liable to cause confusion, because torque is not a force, but the moment of a force, and the radius of its action should always be given.

EXAMPLE FOR PRACTICE

If a motor has a torque of 40 pound-feet, what pull will be exerted at the rim of a pulley 16 inches in diameter?

Ans. 60 pounds.

The torque of a motor may be measured by means of a Prony or friction brake. The arrangement of the apparatus is shown in Fig. 7. *P* is the motor pulley, *A* and *C* blocks of hardwood clamped against it, the pressure being regulated by the wing-nuts *e e*. The lever *L*, which may be of any convenient length, is counterbalanced by the weight *w*. When the pulley rotates in the direction of the arrow, the friction on the blocks tends to raise the weight *W*; and by adjusting the pressure on the blocks and varying *W*, a balance may be obtained, so that *W* when hanging free just neutralizes the tendency of the lever *L* to revolve. The torque of the motor is then $W \times R$, where *R* is the perpendicular distance from the axis of the shaft to the line of support of *W*.

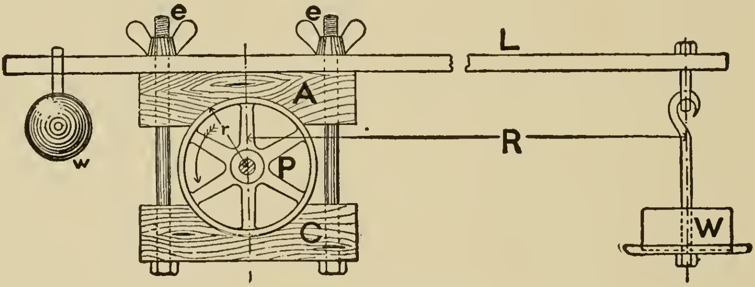

Fig. 7. Friction Brake.

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* The term *foot-pounds* should not be used in this connection, for the foot-pound is a commonly used unit of work, and torque by itself is not work.

To find the torque when the motor is running at a certain speed or is taking a certain current, the nuts *e e*, must be adjusted until the speed or current is as desired, preventing the lever *L* from revolving by stops, and then varying *W* until a balance is obtained, when the stops are taken away. In making the measurement, it may be necessary to allow a little water to run upon the inside of the pulley, to absorb the heat generated by the friction. The wood blocks run best when dry, and a little smoke does no harm to the measurement. Instead of an adjustable weight *W*, a spring balance is more convenient. This is a very satisfactory method of testing small motors; for large ones, the heat is too great to be readily dissipated unless a special pulley is used which will hold water inside the rim.

The *power* of a motor is the product of the torque and the speed. For, if a force *W* acts at the end of an arm *R* fastened to a shaft, in one revolution the distance traversed by the point of application of the force is 2π R, and the work done $2 \pi R \times W$. In the case represented by Fig. 7, the work done by the revolving shaft is the same as if a weight *W* were being continually wound up on a pulley of radius *R*. If the shaft revolves *N* times per minute, the work done per minute is $2 \pi R W \times N$; or, since RW is the torque, we may write:

$$\text{Power} = 2 \pi \times \text{Torque} \times \text{Speed.} \quad \ldots\ldots\ldots \quad \textbf{(5)}$$

Denoting the torque by *T*, we have the further result:

$$\text{Horse-Power} = \frac{2 \pi T N}{33{,}000} \quad \ldots\ldots\ldots \quad \textbf{(6)}$$

From Equations 5 and 6, it follows that different motors of the same power may have very different properties. They may give a strong torque at low speed, or a light torque at high speed, or may have intermediate values of both, different kinds of work requiring one property or the other. From the discussion on page 3, it follows that the actual force upon the armature wires depends upon their number and on the strength of the field, and the torque will also vary with the diameter of the armature. A strong torque will therefore be obtained by using an armature of large diameter, with many wires revolving in a strong field; but since these are just the conditions for a high E.M.F., such an armature will generate its full counter-E.M.F. at a lower speed than a smaller armature with fewer wires; that is, for a given voltage, the high-torque armature will run at relatively slow speed.

With the aid of Equation 6, it is a simple matter to measure the output of a motor by the brake.

Example. For a certain motor the distance R was 30 inches, the weight W 12.4 pounds, and the speed 1,400 revolutions per minute. What horse-power was developed?

Solution. Since R must be expressed in feet,

$$T = 2.5 \times 12.4 = 31 \text{ pound-feet.}$$

Substituting this value of T in Equation 6, gives:

$$\text{Horse-Power} = \frac{2 \times 3.1416 \times 31 \times 1{,}400}{33{,}000} = 8.26. \qquad \text{Ans.}$$

EXAMPLE FOR PRACTICE

A 500-volt motor rated at 15 horse-power takes a current of 25 amperes when driving a certain machine. It is then disconnected and fitted with a brake; and a test shows that with $R = 32$ inches, and the wing-nuts adjusted until the current is 25 amperes, the speed is 755 revolutions per minute; and $W = 36$ pounds. What is (*a*) the actual horse-power needed to drive the machine; and (*b*) the efficiency of the motor? Ans. 13.8 horse-power, nearly.
82.3 per cent.

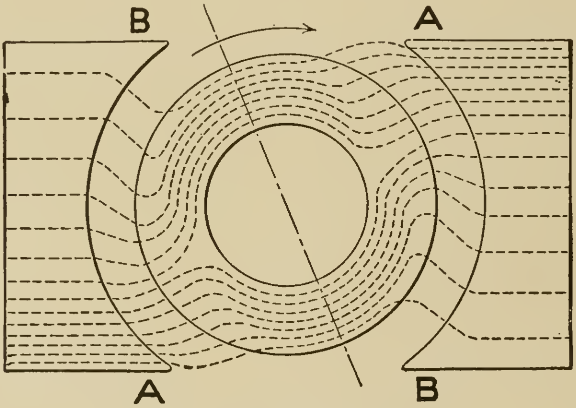
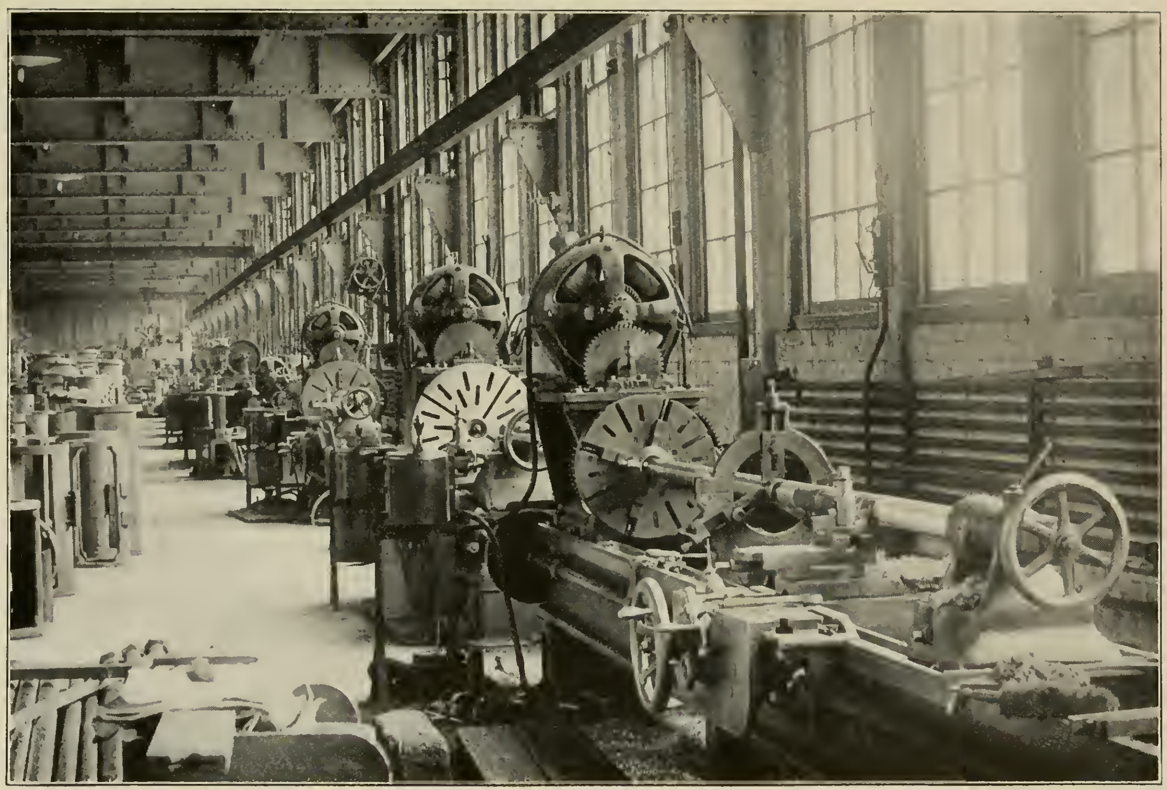


Fig. 8. Armature Reaction in Motor.

Armature Reaction in Motors. In a motor the direction of the armature current, and hence the direction of its magnetic field, are opposite to those in a generator. The resultant field in the motor armature and air-gap will therefore be as shown in Fig. 8. It is evident that the neutral points are shifted backwards, while in a



SHOP INSTALLATION OF INTER-POLE MOTORS DRIVING LATHES ORIGINALLY EQUIPPED WITH CONE DRIVE

Courtesy of Electro-Dynamic Company

generator they are shifted forwards; hence for good commutation the brushes must be shifted *against* the rotation, while in the dynamo they are shifted *with* it. Most motors are required to operate without change of brush lead throughout the entire range of load; and this necessitates careful design, to the end that the field-magnets shall entirely overpower the armature reaction and keep the distortion of the field small, so that commutation may be good with the brushes fixed in position, no matter what the load may be. Many motors, particularly railway motors, must in addition run in either direction; and this requires fixing the brushes at the no-load neutral point. Such motors, however, cannot give as good commutation as those in which the brushes may be set backwards—a fact which is shown by the more rapid roughening and wear of the commutator and brushes. Nearly all motors are operated on constant-potential circuits, and carbon brushes are used almost without exception.

General Speed Formula. The factors upon which the speed of a motor depends can be obtained as follows:

The counter-E.M.F. depends upon the strength of the field f, the number of armature conductors z, and the speed of rotation s. Hence we may write $e \propto s\,f\,z$, or, in the form of an equation,

$$e = k\,s\,f\,z,$$

in which k is a constant depending on the design of the motor. Substituting this value of e in Equation 1, we have:

$$I = \frac{E - e}{R} = \frac{E - k\,s\,f\,z}{R};$$

and, solving for s,

$$s = \frac{E - IR}{k\,f\,z}. \qquad \text{. . . . . (7)}$$

As already stated, IR is only from 3 per cent to 5 per cent of E in motors of ordinary size; and if we disregard it, we may write the simple relation:

$$s = \frac{E}{k\,f\,z}. \qquad \text{. . . . . (8)}$$

That is, the speed of a motor is directly proportional to the E.M.F. at the brushes, and inversely proportional to the number of conductors on the armature and the strength of the field.

Other conditions remaining the same, it is plain that an increase in E will increase the speed, for increased E increases the current and therefore the torque, and the speed must evidently rise as an immediate consequence. But at first sight it is not so clear that the same result will be produced by weakening the field. The reason may be seen, however, by anticipating the result of the calculation on page 20, where it is shown that any reduction of the counter-

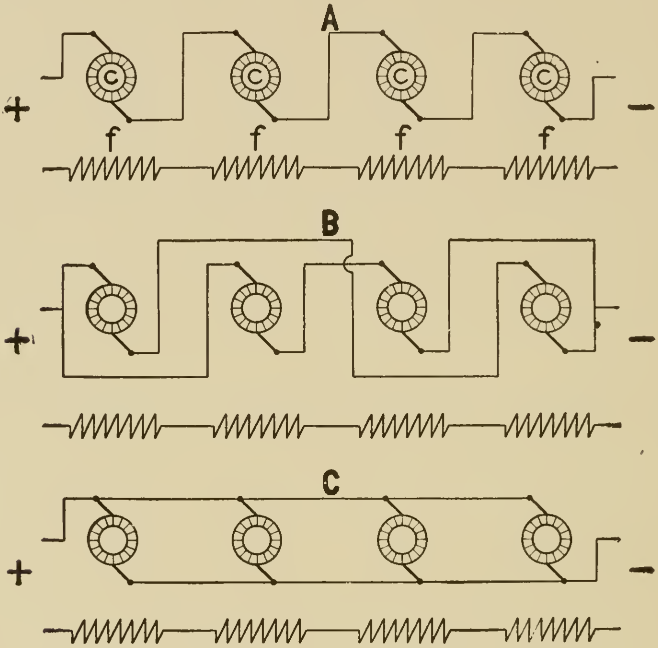


Fig. 9. Series-Parallel Connections of Four Motors.

E.M.F. increases the current in a much greater ratio. In the example there given, reducing the field strength 1 per cent increases the armature current 24 per cent, so that the actual increase in the torque is $\frac{99}{100}$ of 24 per cent (or 23.76 per cent), or practically in proportion to the current. Hence the speed increases, the increased current much more than compensating for the slight diminution in the field strength.

It is often desirable to vary the speed of a motor, and Equation 8 thus gives the three general methods for accomplishing the desired result—namely:

(1) By varying the E.M.F. at the brushes.
(2) By varying the strength of the field.
(3) By changing the number of wires on the armature.

Of these, methods 1 and 2 differ in details with different types of motor, and are discussed under each type. Method 3 is not practicable, since for satisfactory operation it would involve several independent windings, each with its own commutator. But where several motors drive one machine, the same result can be obtained by connecting the motor armatures in series or parallel combinations. Thus two motors may have their armatures connected in series or parallel by a suitable switch or controller; in the first case, half the line E is supplied to each armature; in the second case, the full E. With four motors the connections might be made as shown in Fig. 9, giving speeds in the ratio 1 : 2 : 4 with the arrangements A, B, and C, respectively, the motor fields f being kept constant. In the actual case, however, two-motor or four-motor combinations are used only in railway work; and four-motor sets are operated with the motors connected in pairs, like a two-motor equipment; in the latter case the additional flexibility of operation does not justify the extra complication introduced by taking the four as separate units. In general, this method of speed regulation is favorable to economical working, for the use of wasteful resistances is much reduced; but it does not warrant the installation of two motors when one will do the work.

CLASSES OF MOTORS

The preceding propositions are true for all classes of direct-current motors; but there are also many special properties depending on the relations that exist between the armature and field, so that it is next necessary to classify motors, like dynamos, with respect to the different methods of exciting the field. We have, accordingly:

1. Magneto motors.
2. Shunt motors.
3. Series motors.
4. Compound motors.

Magneto Motors. Because of the difficulty of making them self-exciting, very small dynamos are built with permanently magnetized fields. With motors, however, there is no such difficulty in obtaining the field, so that the magneto motor is not used, except where rotation in one direction or the other is desired by simply reversing the current without further complication. This is sometimes required in light mechanisms or controlling apparatus.

SHUNT MOTORS

To this class belong most of the motors used for all direct-current power service except railway work. The construction and electrical connections are exactly the same as for shunt dynamos, and any good shunt dynamo will make a correspondingly good motor. Shunt motors are practically always operated on constant-potential circuits, and, except at starting, the electrical connections are as shown in Fig. 10, both armature and field being connected across the line. Hence the field current and the field strength will be constant, and the torque will vary directly as the current through the armature, the current itself being determined by Equation 1.

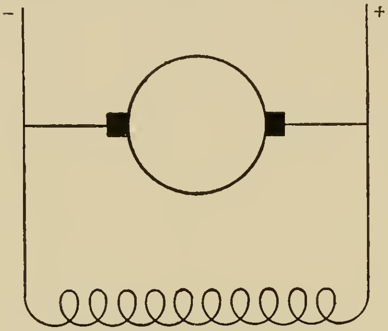


Fig. 10. Connections of Shunt Motor when Running.

The action of the shunt motor may be explained as follows:

Since the counter-E.M.F. varies as the product of the speed, strength of field, and number of armature wires, and the two latter factors are constant in this case, it follows that any change in the speed will cause a proportionate change in the counter-E.M.F. e; but, since e is nearly equal to E (the line E.M.F.), the current through the armature will change in a much greater ratio, a small decrease in the counter-E.M.F. causing a much greater increase in the current, and hence in the power delivered by the motor. For example, if the counter-E.M.F. of a 125-volt motor is 120 volts at a speed of 1,000 revolutions per minute, and the armature resistance is 0.2 ohm, the current at this speed is:

$$\frac{E - e}{R} = \frac{125 - 120}{0.2} = 25 \text{ amperes.}$$

If an additional load is put upon the armature, it naturally slows down. Suppose it to slow down to 990 revolutions per minute. The counter-E.M.F. will then decrease to $\frac{990}{1,000}$ of 120, or 118.8 volts; and the current will rise to:

$$\frac{125 - 118.8}{0.2} = 31 \text{ amperes.}$$

That is, a decrease of 1 per cent in the speed causes an increase of 24 per cent in the current; and the speed will continue to diminish until the current increases enough to supply sufficient power to prevent further speed reduction—that is, until the increased input equals the increased demand. Similarly, a diminished load which will allow the armature to speed up to 1010 revolutions per minute will be accompanied by a decrease of 24 per cent in the current. Small variations of speed like this are not readily noticed; and to the casual observer the motor seems to adapt itself with uncanny knowledge to its work, in taking without apparent effort the precise current for every demand. The explanation lies, as we see, in the fact that only a slight change is needed in the delicate balance between E and e to accomplish the observed result, by speed variations which are usually too small to notice, unless very sudden. If the load should be removed entirely, there is no tendency for the motor armature to race, for every slight increase in the speed increases e and diminishes the flow of current from the line, thus cutting off the power supply when it is not wanted.

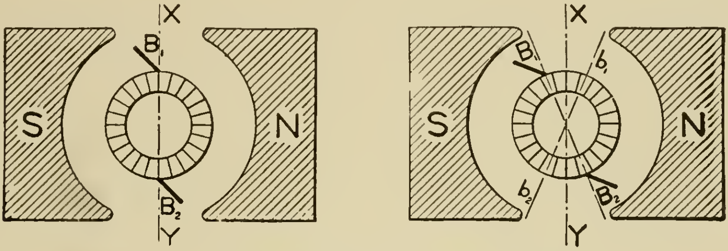


Fig. 11. Demagnetizing Effect of Motor Armature.

The smaller the value of R, the greater will be the change in I for a given change in e; in other words, the smaller will be the variations in speed with changes of load. Since e differs from E by IR, the E.M.F. required to send the current through the ohmic resistance of the armature, and in well-designed machines IR is only from 3 per cent to 5 per cent of E, the speed falls off from no load to full load only by this small percentage; and we have in consequence the very valuable ability of the shunt motor to run at practically constant speed, irrespective of the load upon it. The small variations that actually do occur are not, as a rule, of sufficient importance to warrant special devices for their correction.

EXAMPLE FOR PRACTICE

Calculate the current through the above-mentioned motor when the speed is 1010 revolutions per minute.

Ans. 19 amperes.

Effect of Armature Reaction on Speed. To eliminate sparking, we have seen that it is necessary to shift the brushes of a motor backward, and those of a generator forward. In both cases, there is introduced a demagnetizing belt of conductors, which weakens the field. This is illustrated in Fig. 11, which shows the motor brushes drawn backward from the no-load position. This action creates a demagnetizing belt of conductors lying between B_1 and b_1, and between B_2 and b_2. As the motor is loaded, the field is therefore progressively weakened by the increased current through this belt of conductors, and the counter-E.M.F. reduced correspondingly, which tends to increase the speed. Thus, by giving considerable backward lead to the brushes, it is possible to obtain nearly constant speed at all loads. Not all motors are designed to operate with so great a lead as this would often require; but the effect is always present in some degree, to the further advantage of the constant-speed tendency of the shunt motor.

Speed of Shunt Dynamo Used as Motor. If a shunt dynamo is used as a motor on a line of the same voltage, its speed as a motor will be less than when generating the line voltage as a dynamo. To find what the motor speed will be, we may proceed as follows:

To supply I amperes to the line at E volts, E_d, the E.M.F. generated in the armature, must be $E_d = E + IR$, where R is the armature resistance, because some of the E.M.F. generated is expended in sending the current through the armature itself. The E.M.F. generated in the armature of the same machine used as a motor is, from Equation 1:

$$e = E - IR.$$

Since the field strength is the same in the two cases, both being supplied at E volts, the armature E.M.F.'s will be directly proportional to the speed; or,

$$\frac{\text{Motor Speed}}{\text{Dynamo Speed}} = \frac{e}{E_d} = \frac{E - IR}{E + IR} = 1 - \frac{2\,IR}{E_d}, \text{ approximately.} \quad . . (9)$$

Since $\frac{IR}{E}$ lies ordinarily between 0.03 and 0.05, as we have seen, it follows that the speed of a given machine as a motor will be generally from 6 per cent to 10 per cent less than its speed as a dynamo. If, however, the field strength is not constant, either because of armature reaction or changes in the field current, the relation, of course, ceases to hold.

EXAMPLE FOR PRACTICE

A certain dynamo is rated at 25 kilowatts at 220 volts and 600 revolutions per minute. Its armature resistance is 0.08 ohm. What is its full-load speed as a motor? ANS. 550 r.p.m.

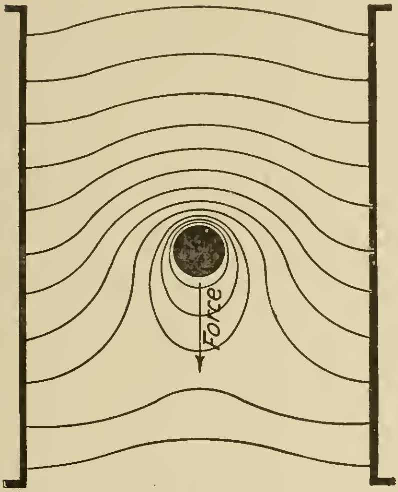


Fig. 12. Force on Dynamo Armature Conductor Moving Upward.

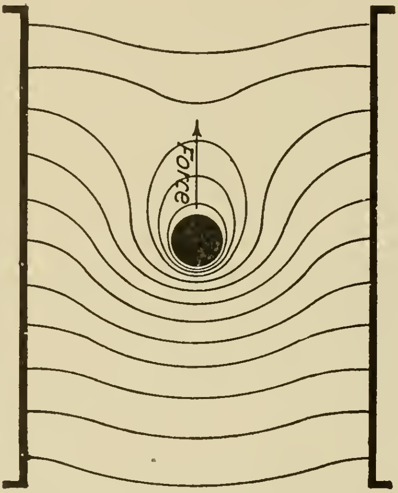


Fig. 13. Force on Motor Armature Conductor Moving Upward.

Direction of Rotation of Shunt Motor. To examine the behavior of a shunt dynamo used as a motor, a modification of Fig. 3 may be used. Fig. 3 gives the general directional relations between the field, current, and force upon an armature conductor; and Fig. 12 represents the case of a wire on a dynamo armature, moving toward the top of the page, the current creating a force on the wire which is against the direction of the motion, so that power is required to keep up the rotation. Now, if the machine is used as a motor driven by current from the same line, the direction of the field remains the same; but the current through the armature is reversed, and the field of Fig. 12 will be changed to that of Fig. 13. The force on the armature wires is reversed, and is now in the direction of the rotation, instead of against it as in the dynamo; consequently the armature will rotate in the direction of its rotation as a dynamo. The reversal of the current through the armature, and not through the field, is shown in Fig. 14.

This property is of considerable importance when shunt dynamos are operated in parallel. If reduced speed should cause the E.M.F. of any machine to fall slightly below the line E.M.F., the armature merely continues to revolve in the same direction as a motor, and no harm is done.

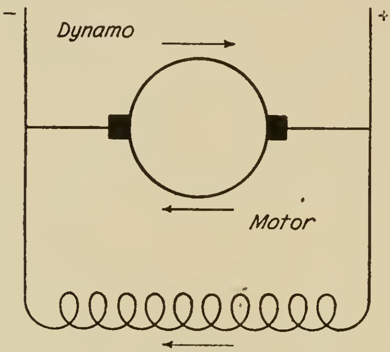


Fig. 14. Direction of Current in Shunt Dynamo and Motor.

To convert a shunt dynamo into a motor, therefore, if the direction of rotation is to remain the same, no change whatever is necessary. A starting rheostat must be added, but the machine itself needs no alteration.

The Starting Resistance. Very small motors are started by simply closing the switch that connects them to the line. No further apparatus is necessary, especially if they are series-wound, as is frequently the case to save the expense of a fine-wire shunt winding. For motors larger than about one-quarter of one horse-power, at full speed, the counter-E.M.F. prevents the current from exceeding safe values; but at starting, e is of course zero; and since R is always very small, the rush of current that would take place on throwing the full line voltage upon the motionless armature would blow out all the fuses, or might damage the armature or even the line itself. Hence it becomes necessary to insert a resistance temporarily in the armature circuit, cutting it out gradually as the speed rises. Such a resistance is called a *starting rheostat* or *starting box.*

The diminution of current through the armature as the speed increases may be easily shown by putting an incandescent lamp of about 50 candle-power in series with the armature of a small motor. Fan motors are usually series-wound; and with such it is enough to put the lamp anywhere in the circuit between the motor and the line. When the switch is closed, the lamp burns brightly for a moment and then grows dim as the armature speeds up, showing that under these conditions the starting current is much greater than the running current. The resistance of such small motors is high enough to prevent damage to the motor during the two or three seconds required to come to full speed, even though no starting resistance is used.

The starting box itself consists mainly of a resistance divided into small sections and arranged with suitable contacts so that by moving the arm of a switch the sections can be cut out one after another. At full speed, the entire resistance is cut out, and the full line E.M.F. is applied to the armature terminals. The resistance itself is made of iron wire or ribbon, wound upon asbestos-insulated tubes or strips, or embedded in insulating enamel.

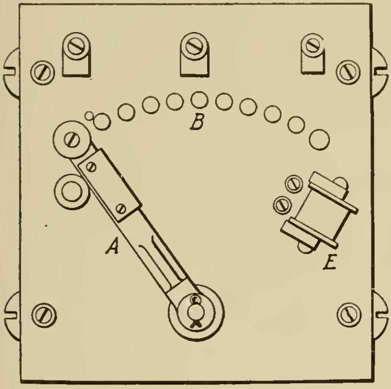


Fig. 15. Face of Starting Box.

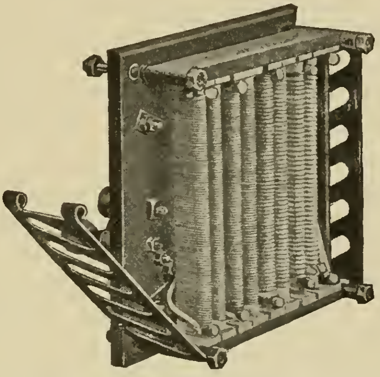


Fig. 16. Interior of Starting Box. Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

The face of such a rheostat has the general appearance shown in Fig. 15, which shows the movable switch arm *A*, the row of contact studs *B*, and a small magnet *E* whose function will be explained later. The interior of a rheostat is illustrated in Fig. 16. One side and the bottom of the box are shown removed for inspection of the resistance coils or for repairs.

When the motor is of 50 horse-power or over, the sparking that always occurs at the contact-studs soon burns them and causes trouble, and the form of rheostat shown in Fig. 15 is being superseded by a type in which the sections of the resistance are cut out by separate switches. One such form is shown in Fig. 17. The cut represents a multiple-switch starter for a 500-horse-power, 220-volt motor.

The first switch on the left is held closed by an electromagnet through which the field current passes; and the other switches are held by latches. Each switch has upon it a metal plate which prevents closing it until the switch at its left has been closed; and the interlocking mechanism thus obtained prevents a careless operator from closing the switches in the wrong order. When the current is cut off, the switch on the left is opened automatically by a spring, and this frees the switch next to it; this opens in turn; and so on until all have opened, when the apparatus is ready for starting the motor again.

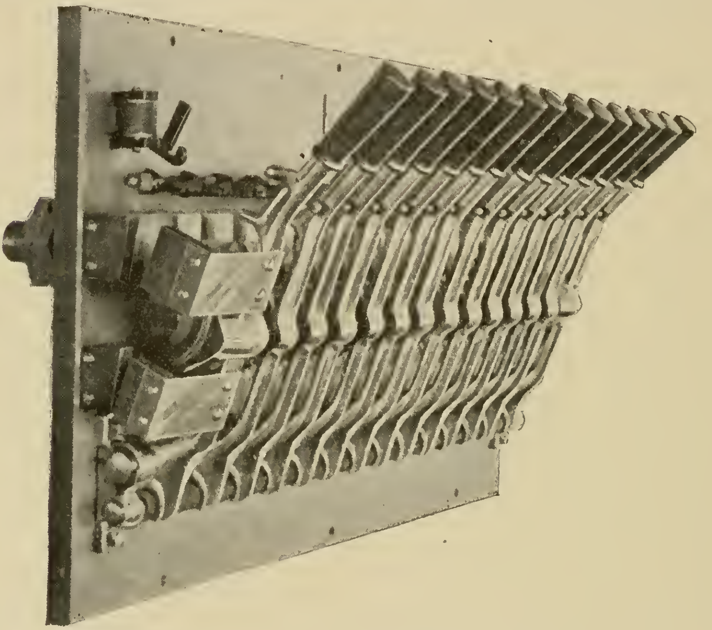


Fig. 17. Front of Multiple Switch Motor Starter, with Automatic Release.
Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

In starting motor-generator sets, rotary converters, and other apparatus where the starting current is only a small fraction of the running current, it is desirable to cut out the entire starting mechanism after full speed is attained. In such cases a simpler starting device is often used, of relatively small capacity and without automatic attachments. One form of such starting device is shown in Fig. 18. The picture shows clearly the way in which the steps of the resistance are cut out as the switch-blade is slowly pushed home. This switch is placed on the general switchboard of the apparatus, and the resistance mounted separately.

The maximum resistance R of the starting rheostat is determined by the equation $R = \frac{E}{I}$, where I is the current required to start the motor. Frequently motors must start under load, and the necessary starting current is considerably greater than the normal full-load running current—sometimes two or three times as much. Any good motor will safely endure this overload for the 15 or 30 seconds required to come up to speed; and many starting rheostats are designed to carry for this time a 50 per cent excess over the full-load motor current. But when a greater starting current than this is needed, or when it is desirable to allow the motor a minute or more in which to come up to speed, the ordinary starting rheostat is liable to overheat, and one of larger size must be installed. With a [illegible] designed to start the motor under load, the speed will rise rather quickly if the motor is not loaded; but this does no harm if the current is not excessive.

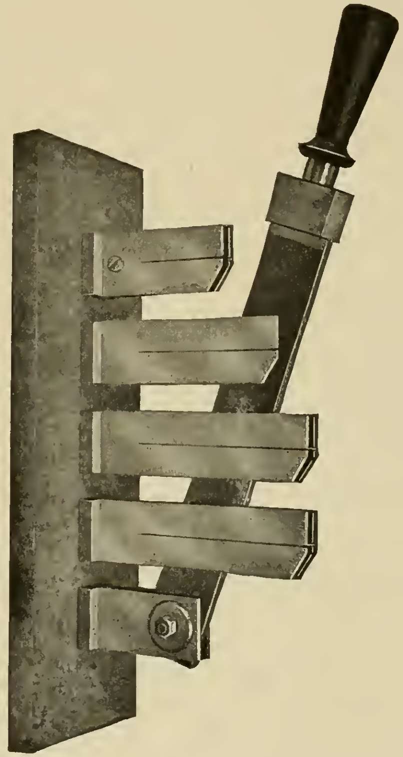


Fig. 18. Multi-Point Switch.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

Electrical Connections of Shunt Motor. Fig. 19 represents perhaps the simplest method of wiring a shunt motor and starting rheostat on constant-potential mains. From the line, the wires lead through a fuse-block F and a double-pole switch S. If the motor is a large one, a circuit-breaker is better than fuses. On tracing out the connections, it will be seen that when the switch S is closed the current flows through the motor fields. With the rheostat arm a in the position shown, no current flows through the armature; but on moving the arm to the first contact, the armature circuit is closed through the resistance *R*, which is gradually cut out as the handle is moved to the left. Opening the main switch cuts off the line current, but leaves the field connected across the armature terminals, as in a dynamo; so that, as the motor comes to rest the fields die down gradually without the destructive flash that would occur if the field circuit were opened suddenly while the magnets are excited. For this reason the field circuit should not be opened first.

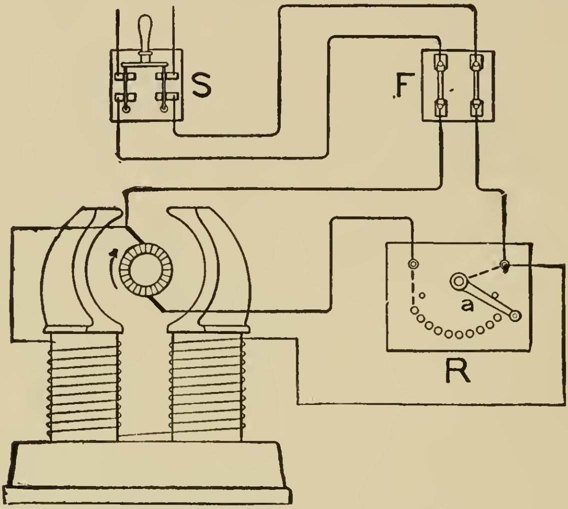


Fig. 19. Wiring Connections of Shunt Motor.

When the armature has come nearly to rest, the rheostat arm is restored to the original position, and the motor is ready for starting again.

Automatic Release. The preceding diagram has been drawn to reduce the principle to its lowest terms and to keep the drawing clear; but in practice the simple rheostat shown is seldom used. After the motor is shut down by opening the main switch, the rheostat lever must be moved back by hand, to the starting position; and this is an operating detail that is very easily forgotten. Consequently, when the motor is to be started again, the position of the arm may not be noticed, and damage may be done by closing the switch with no resistance in the armature circuit. Furthermore, the power supply may be cut off and the line may become "dead" while the motor is running, whereupon the motor stops of itself with the rheostat arm in the running position as before. It is therefore the almost universal custom to install rheostats which are arranged to allow the arm to fly back automatically to the off position whenever the power is shut off from the motor. One method of accomplishing this is to connect the auxiliary or retaining magnet shown in Fig. 15 in series with the motor fields, the rheostat arm being provided with a spring tending to throw it back into the off position. When in the running position, as shown, the iron arm is held by the attraction of the magnet against the force of the spring; but when the motor loses its field, the magnet loses its power, and the spring carries the arm back into the off position. The retaining magnet is placed in series with the field rather than the armature, because it is thus independent of the load on the machine, and in addition affords protec-

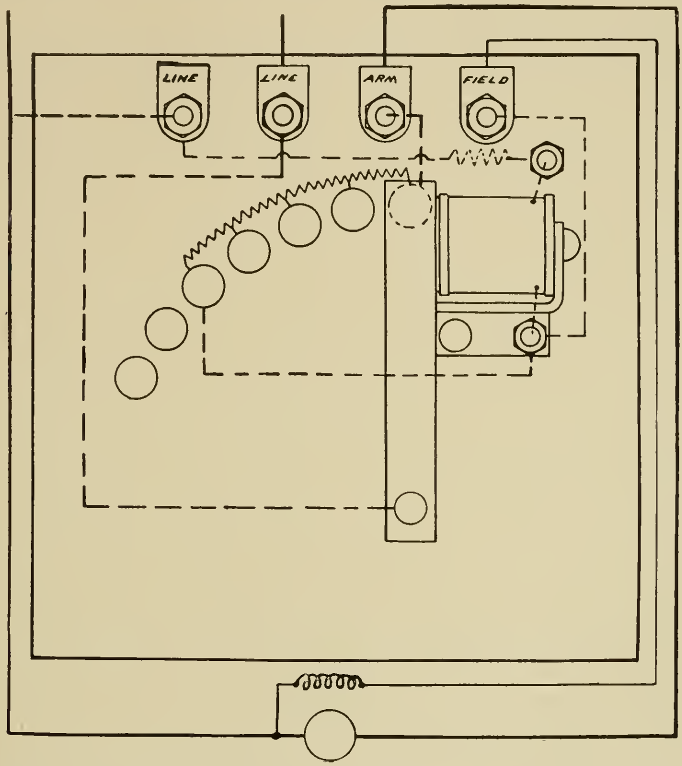


Fig. 20. Connections of Motor-Starting Rheostat with No-Voltage Release.

tion in case the field circuit should be broken while running, thus leaving the armature without any counter-E.M.F.

There are other ways of accomplishing the same result. The one shown in Fig. 20 represents a method of connection employed by the General Electric Company. Here, as may be seen by tracing out the connections, the retaining magnet is connected across the armature terminals. When the line circuit is opened, the rheostat arm is held by the current generated in the magnet-coils by the armature E. M. F., until, as the armature slows down, the magnet weakens, and the spring pulls the arm over into the starting position.

Wiring Connections. Figs. 15 and 19 are typical. The ordinary starting rheostat has three terminals, which are usually marked *Line, Armature,* and *Field* or *Shunt Field.* There are four terminals on the motor (*a, b, c, d,* Fig. 21)—two for the armature and two for the field; but one armature and one field terminal are always at the same potential and may therefore be connected, leaving three separate terminals *c′, a,* and *b* on the motor, which may be called *Line, Armature,* and *Field,* respectively.

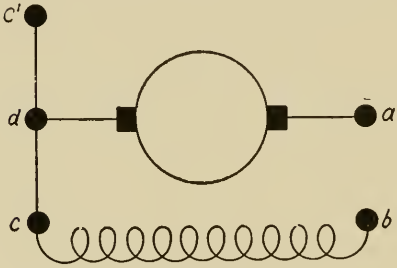


Fig. 21. Motor Field and Armature Terminals.

If the rheostat terminals are marked as above, the wiring of a shunt motor then becomes a simple matter. After putting in the fuses and double-pole switch, first run a wire from one pole of the switch to the rheostat terminal marked *Line.* Run a second wire from the *Armature* terminal of the rheostat to the free terminal *a* of the motor armature, and a third wire from the *Field* terminal of the rheostat to the free terminal *b* of the motor field. This wire, which carries only the field current, may often be made smaller than the others. Finally, run a wire from *c′*, the common terminal of the motor field and armature, back to the other pole of the switch.

A common mistake in wiring consists in interchanging the *Line* and *Armature* wires at the starting box. On the first contact-stud, this puts the field across the brushes and therefore in parallel with the armature, both being in series with the starting resistance. Hence, since most of the line E.M.F. is expended in the resistance, there is very little across the terminals of the field winding and the armature; and the field is consequently so weak that the motor may not develop sufficient starting torque unless the current is large enough to injure the starting box. This is one of the first places to look for the trouble, if a motor does not start properly when first installed.

There are several methods of arranging the connections inside the starting box itself, as shown in Fig. 22, in which the retaining magnet *E* is drawn outside the box for clearness. It will be noticed that the only difference is in the connection of the field circuit. In the upper diagram, closing the switch establishes the field circuit; while in the lower diagram, no current flows until the rheostat arm is moved to the first stud. In the lower diagram the starting resistance is always in the field circuit; but its resistance is so small compared with that of the field coils that its effect is not noticed. By an auxiliary contact *m*, the resistance is sometimes cut out entirely. The little magnet *E* takes only a few watts, and is without effect on the operation of the motor.

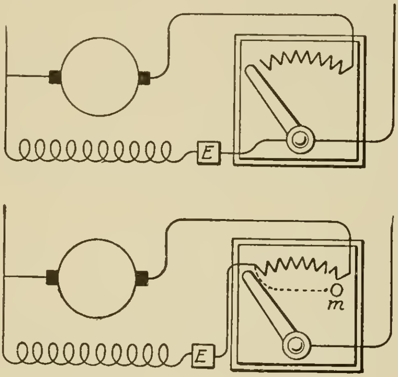


Fig. 22. Starting-Box Connections.

Overload Release. This is a useful addition to the starting box, for the purpose of cutting the motor out of circuit when the armature current becomes excessive, without relying on the fuses or circuit-breaker. It consists of a second electromagnet through which the armature current passes, mounted on the face of the starting box, and provided with a movable armature which hangs down like a hinge below the magnet-poles. When the current exceeds the proper strength, the armature is lifted by the attraction of the magnet and presses against little contact-pins, short-circuiting the release magnet holding the rheostat arm, whereupon the arm at once flies back to the off position.

This device is not intended to be used as a substitute for the fuses, but is adjustable and useful for taking care of overloads not exceeding about 50 per cent. Heavier fuses may then be used, giving the necessary protection but saving the annoyance of frequently blown fuses. Fig. 23 shows the connections of a rheostat equipped with an overload release of this type.

OPERATION OF MOTOR

To Start the Motor. In starting the motor, the following directions are to be observed:

1. Close the main switch. According to the method of connection, as shown in Fig. 22, this will either establish the current through the field, or will merely bring the line voltage up to the starting box.

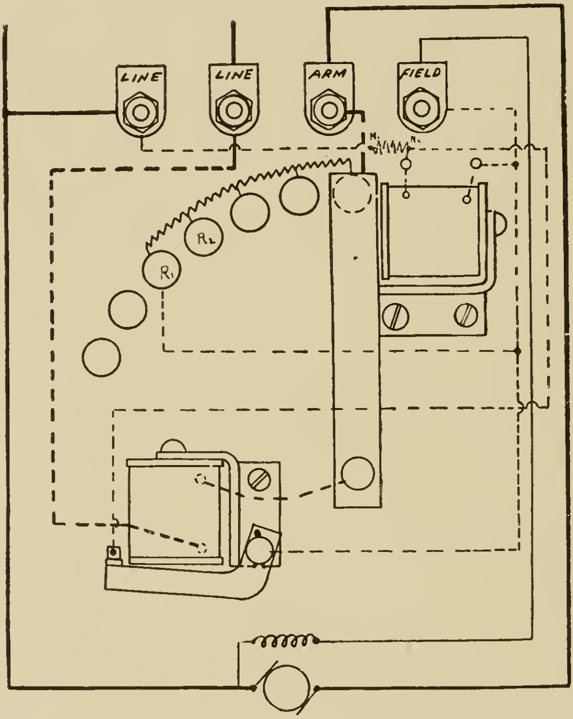
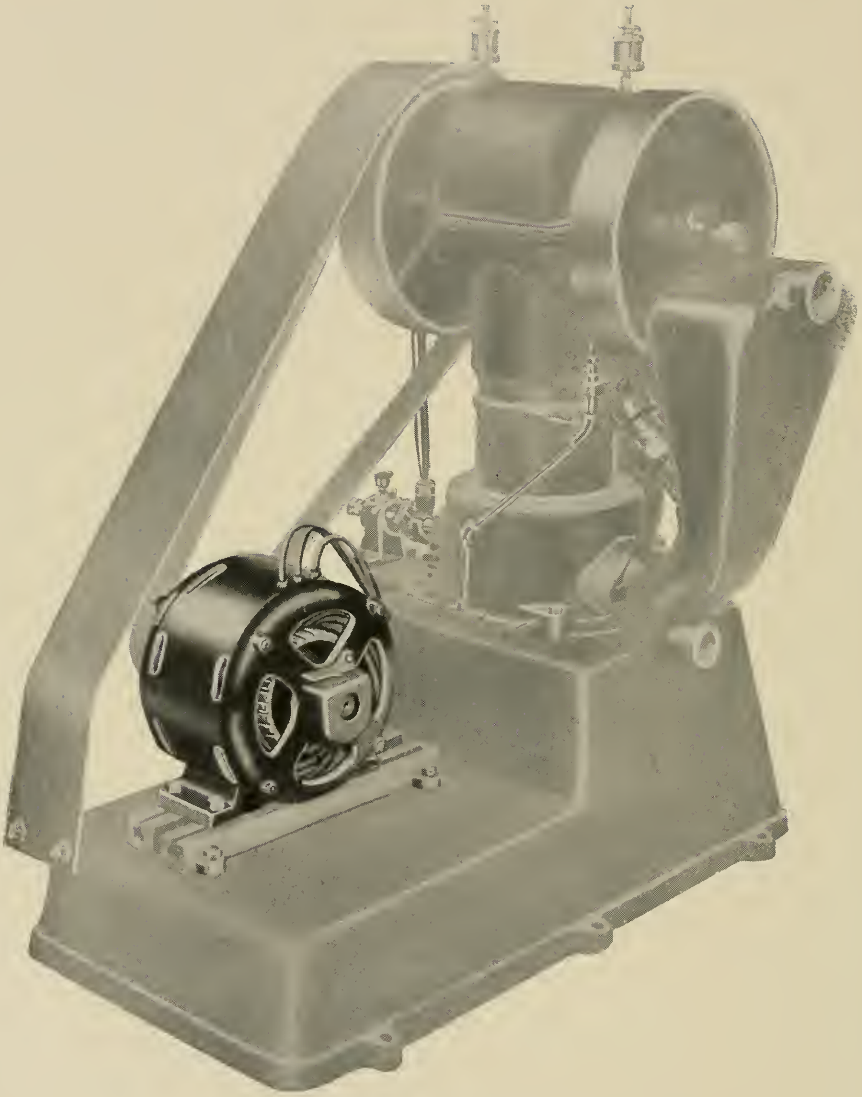


Fig. 23. Connections of Motor-Starting Rheostat with No-Voltage and Overload Release.
General Electric Company, Schenectady, N. Y.

2. Move the rheostat lever to the first contact, and hold it there for one or two seconds.

3. Move the lever to the second stud, and hold it there for about one second; and so on, until all the studs have been passed



RICHMOND POLYPHASE MOTOR BELTED TO A PUMP

Courtesy of Richmond Electric Company

over and the resistance is short-circuited. The lever should then be firmly held by the retaining magnet. The entire operation should not consume more than 15 to 30 seconds.

If the motor does not start when the lever is on the third stud, open the main switch, and look for the trouble. It may be due to one or another of the following causes:

1. Overload.
2. An open circuit somewhere.
3. A short circuit somewhere.
4. Wrong connections.

No cause of motor trouble is more common than simple overloading. Always at the time of installation, and occasionally thereafter, an ammeter should be connected into the motor circuit, and its reading compared with the rated current of the motor. Motors are designed to do their work with but little attention. They frequently get none at all; belt, commutator, and bearings are neglected; additional machinery is put into the shop and operated from the original motor; and so on—with the inevitable result of overload.

The methods of locating troubles and remedying them, and of caring for dynamo-electric machinery in general, are matters of such importance that their full discussion requires treatment in a separate paper.

To Stop the Motor. Open the main switch. The motor will run for a little time by its own momentum, and the retaining magnet will not allow the rheostat arm to fly back until the armature has slowed down considerably. If the contact-studs are dirty, the lever may not move readily over them; and if it does not fly back sharply, they should be cleaned, and the spring on the lever adjusted if necessary.

Reversing Direction of Rotation. Most motors are now built with radial brushes, and may rotate equally well in either direction. To reverse the rotation, it is necessary to change the direction either of the field or of the armature current, but not of both, since the double reversal would be equivalent to turning Fig. 3 over twice, leaving the force upon the armature, and consequently the rotation, in the same direction as before.

To allow easy connection for rotation in either direction, some motors are provided with separate field and armature terminals, as shown in Fig. 24. The direction of the armature current can then be reversed by changing the connections as shown.

In motors which are to be reversed while in operation, the armature connections are the ones changed, because this causes less severe strains on the insulation than reversing the highly inductive field circuit. If the motor is merely to be reversed once for all, the brushes should be shifted to the proper lead on the other side of the no-load position; but if it must run in either direction while at work, of course no lead can be given to the brushes, and they must be fixed permanently in the no-load position.

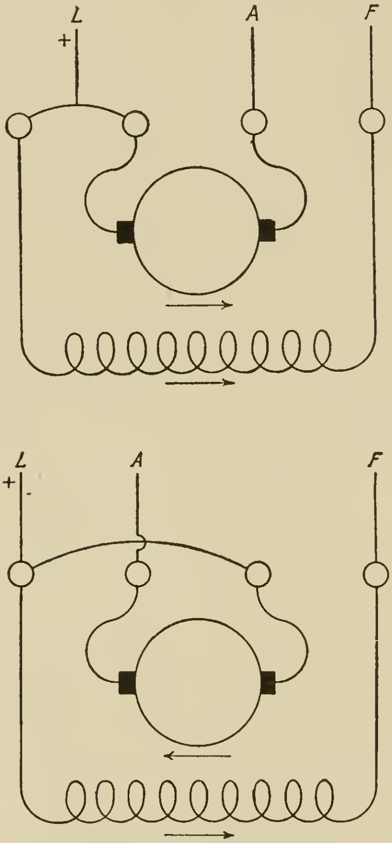


Fig. 24. Connections for Reversing a Motor.

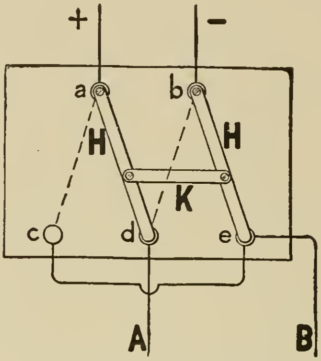


Fig. 25. Reversing Switch.

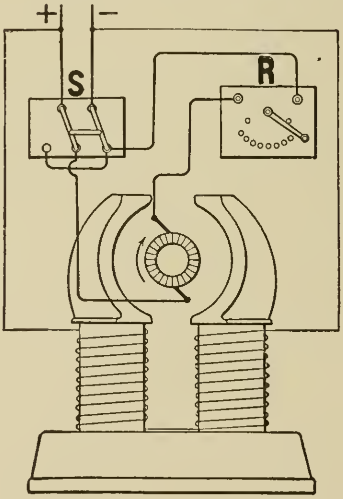


Fig. 26. Connections of Reversing Switch.

A motor should never be reversed while running, except for the most necessary reasons, and then not until the full resistance is inserted in the armature circuit. For with the line E.M.F. reversed, the counter-E.M.F. of the armature is for a moment added to that of the line, and the excessive current that flows brings the armature to a stop with a severe jolt that is very likely to cause damage.

Fig. 25 shows one form of reversing switch; and Fig. 26, the manner of its connection into the armature circuit. In Fig. 25, *H* and *H* are brass bars pivoted at *a* and *b*, and connected by a fiber cross-piece *K*. As shown, they are in contact with the studs *d* and *e*. When *K* is moved so as to bring the bars on the studs *c* and *d*, as shown by the dotted lines, it is easy to see that the current will be reversed in the circuit *AB*.

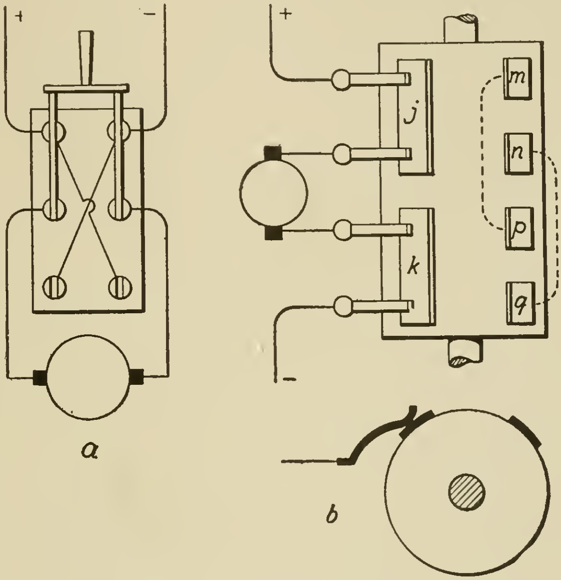


Fig. 27. Reversing Switches.
a—Knife Switch; *b*—Cylinder Switch.

Fig. 27 shows, at *a*, a simple and satisfactory reversing switch made by cross-connecting the clips of an ordinary double-pole, double-throw knife switch. The line circuit is connected to the clips; the circuit to be reversed is connected to the switch-blades; and simply throwing the switch up or down accomplishes the result.

At *b* in Fig. 27 is shown the principle of cylinder construction which, in a more elaborate form, is much used for speed controllers. In the diagram, an insulating cylinder carries two rows of contact-blocks against which spring contact-fingers press, connected to the various terminals of the motor circuit. When the cylinder is turned to bring the blocks *j* and *k* into contact with the fingers, the current will flow downwards through the motor armature; and with the blocks m, n, p, and q in contact, the current will flow upwards. It is obvious that this arrangement may be extended to execute much more complicated combinations of circuits, by the use of more fingers and more rows of contact-blocks; and in a highly developed form it is widely used for controlling the motors of street-railways.

Automatic Starters. The control of a motor from a distance usually involves the necessity of a *self-starting apparatus*, by which all the motions of the starting rheostat are automatically performed on closing the distant control switch. The movement of the rheostat arm is effected by a solenoid, and the rate of its motion is governed by a dashpot filled with oil. A valve in the dashpot allows the total time of the motion to be varied as required; or thick or thin oil may be used for the same purpose. Perhaps the most common instance of this kind of service is the supply of open tanks with water, and closed reservoirs with compressed air. In the first case, a float switch starts the pump when the water falls below a certain level, and stops it when the tank is full; in the second case, the pressure must be kept within certain limits, and a diaphragm valve makes and breaks the control circuit.

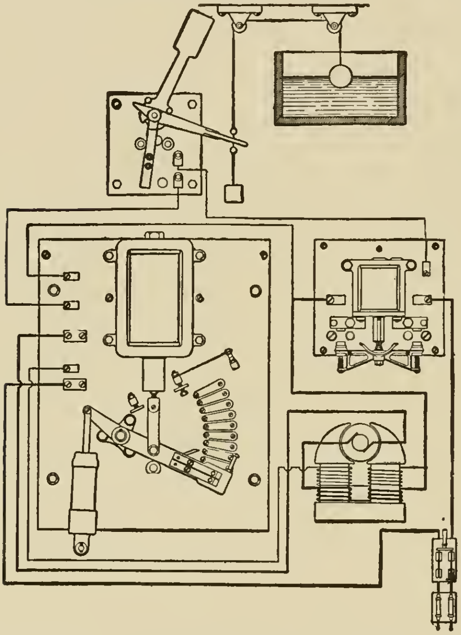


Fig. 28. Self-Starter Used with Motor-Driven Pump.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Fig. 28 shows a self-starter operated by a float switch. This switch, when closed, energizes the solenoid of the main switch shown above the motor in the diagram. Closing the main switch also energizes the solenoid on the rheostat arm, and the arm rises, thus starting the motor. At the end of its travel, the arm breaks a contact, and by so doing inserts an incandescent lamp in the circuit of the solenoid, preventing overheating, a small current being enough to hold the arm in place. The motion of the arm also inserts a lamp resistance in the circuit of the main switch solenoid, as a safety device. For if the main switch is opened, and then closed before the rheostat arm has inserted all the resistance into the motor circuit, the rush of current might blow the fuses; but the lamp is short-circuited only in the off position of the arm; and only under these conditions is the current strong enough to lift the plunger and close the switch.

Reversing Starters. Lathes and other machine tools must often run backwards as well as forwards. Fig. 29 shows a starting apparatus designed to meet this condition. It is in effect a pair of starting rheostats, designed to bring the motor to full speed in either direction. When the handle is in the middle position, the motor is cut out of circuit; and moving the handle to one side or the other starts the motor forward or backward correspondingly.

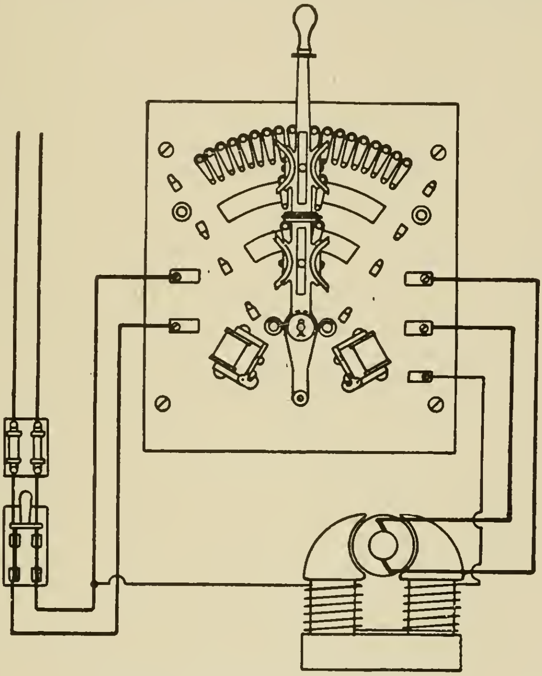


Fig. 29. Full Reverse Motor Starter. Cutler-Hammer Mfg. Co., Milwaukee, Wis.

SPEED CONTROL OF SHUNT MOTORS

Varying E.M.F. at Brushes. A wide range of speed is easily obtained by simply inserting a suitable resistance in the armature circuit, as indicated by R, Fig. 30, leaving the field circuit FF unchanged. The amount of resistance inserted in order to obtain the desired speed and torque can be calculated in several ways.

Example. A certain 110-volt shunt motor takes 75 amperes at full load, at a speed of 700 revolutions per minute. What resistance must be put in series with the armature to obtain half-speed at two-thirds of the full-load torque?

Solution. In Equation 7 (page 17),

$$s = \frac{E - IR}{k\,f\,z},$$

R includes not only the armature resistance, but any other resistance that may be in series with it. At full speed there is no resistance in the armature circuit, except that of the armature itself; and this is negligible in problems like these, so that in this case we may write:

$$s = \frac{E - 0}{k\,f\,z} = 700 = \frac{110}{k\,f\,z}\text{; whence } k\,f\,z = 0.157.$$

The torque at the new speed will obviously require two-thirds of 75 amperes, or 50 amperes. Therefore, using Equation 7 again,

$$s = \frac{E - IR}{k\,f\,z} = 350 = \frac{110 - 50\,R}{0.157}\text{; whence } R = 1.1 \text{ ohms, nearly.}$$

For a more exact solution, the armature resistance should be known; but the above method is quite accurate enough for all ordinary cases.

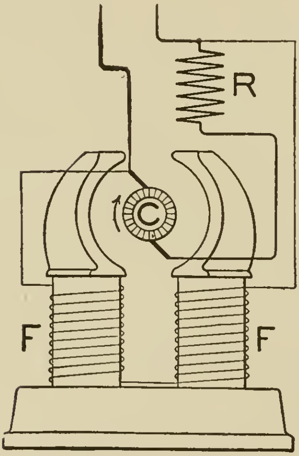


Fig. 30. Speed Control by Resistance in Armature Circuit.

The above method of speed control has the advantage of simplicity, cheapness, and wide range. It is objectionable, however, when the load is fluctuating, for the E.M.F. at the armature terminals, and hence the speed, depend upon the IR loss in the resistance; and IR of course varies with every change in I. Thus, whenever the load increases, the speed will decrease, and conversely; and this is objectionable in many classes of work. A second objection is that the voltage taken up in the resistance represents just so much power wasted, the loss in watts being simply I^2R. With a large motor, this loss may be a somewhat expensive matter; with a small one, the simplicity and convenience largely offset the cost of operation.

EXAMPLES FOR PRACTICE

1. The full-load current of a 250-volt motor is 20 amperes, and the speed 800 revolutions per minute. What resistance is required in series with the armature, to give $\frac{3}{4}$-speed with $\frac{1}{2}$-full-load torque?

Ans. 6.25 ohms.

2. What is the power loss in the resistance added to the 110-volt motor discussed above? Ans. 2,750 watts.

3. What fraction of the power supplied to the 250-volt motor above discussed is wasted in the added resistance?

Ans. 25 per cent.

It is important to note that for the above purposes the starting rheostat must never be used. The specific heat of the materials of the rheostat is utilized to keep its temperature within safe limits during the brief time required for starting. The box is not large enough to dissipate much heat, and, if used as a speed controller, would burn out in a very short time. Resistances used to dissipate much energy continuously, must have liberally proportioned surfaces and free ventilation. Small ones are usually made of iron wire, larger ones of iron ribbon, wound on asbestos supports to expose as much surface as possible to the air; very large ones are made of zigzag strips of cast iron, called *grids*. Fig. 31 shows single grids of various sizes. As many elements as needed are assembled in iron frames.

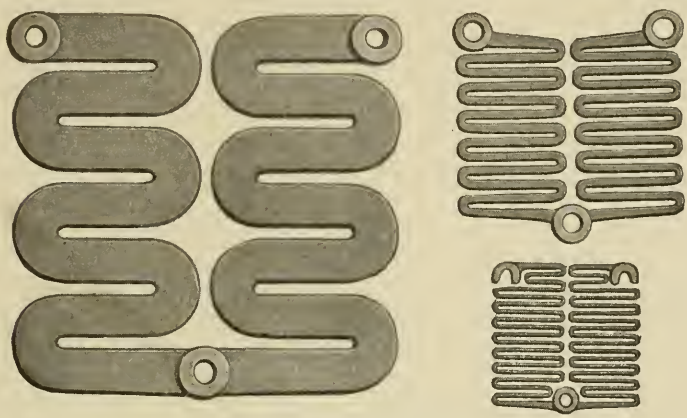


Fig. 31. Standard Grids.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

Speed Control by Varying Field. This method is very simple in principle, and wastes but little energy in the controlling resistance. By varying a resistance in series with the field windings of a shunt motor, the field, and hence the speed, are controllable to a certain extent. The advantage of this method of control is in its simplicity, and in the fact that since the field current is small, there is but little energy wasted and little heat to dissipate from the rheostat. Further, the speed is adjustable by small steps. The disadvantage of the method arises from the fact that the field must not be weakened below the point of satisfactory commutation. This, with an ordinary motor, limits the speed variation to about 25 per cent, or perhaps 30 per cent. If a greater range than this is required, a larger and heavier field-magnet must be provided; for example, for a 2 to 1 variation, a 15-horse-power frame should be used for a 10-horse-power motor, while a 3 to 1 variation requires a 20-horse-power frame for a 10-horse-power motor, with other sizes in proportion. This, of course, means a motor of large size in proportion to its output. The torque diminishes with the weakened field, and this is just compensated by the increased speed, so that the motor runs with practically constant horse-power output. For

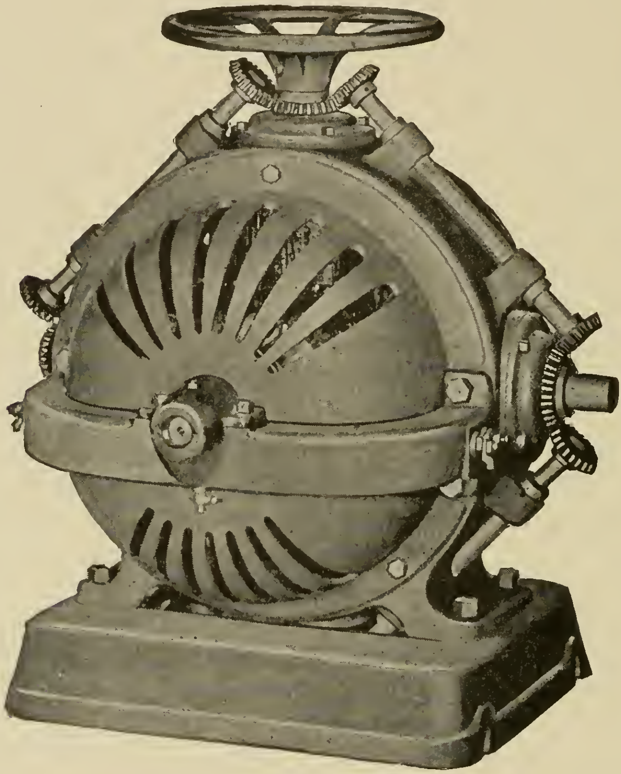


Fig. 32. Variable-Speed Motor.
Stow Manufacturing Co., Binghamton, N. Y.

still greater speed variations, special constructions are used, which will be described later. Fig. 43 (page 52) shows an adjustable-speed motor giving a 3 to 1 variation in speed by variation of field resistance.

Apart from the extra size of the motor, speed control by this system is very satisfactory where conditions do not warrant the installation of a multiple-voltage system.

Control by Varying Magnetic Reluctance. If the reluctance of the magnetic circuit is varied, the field strength will vary though the field current is kept constant. Advantage of this is taken in the motor illustrated in Fig. 32. In this machine the field cores and poles are hollow and provided with iron plungers, which can be moved toward the armature or away from it by a hand-wheel operating suitable gearing. The advantage of this construction is that, when the plungers are withdrawn, the magnetic flux is obliged to enter the armature through the edges of the pole-pieces; and hence, even with the weakest total field, the actual distribution is always such as to give proper commutation. Moreover, the armature reaction is reduced with weak fields, because iron is removed from the path of the cross-flux, and this also assists commutation. A 3 to 1 speed variation is obtained.

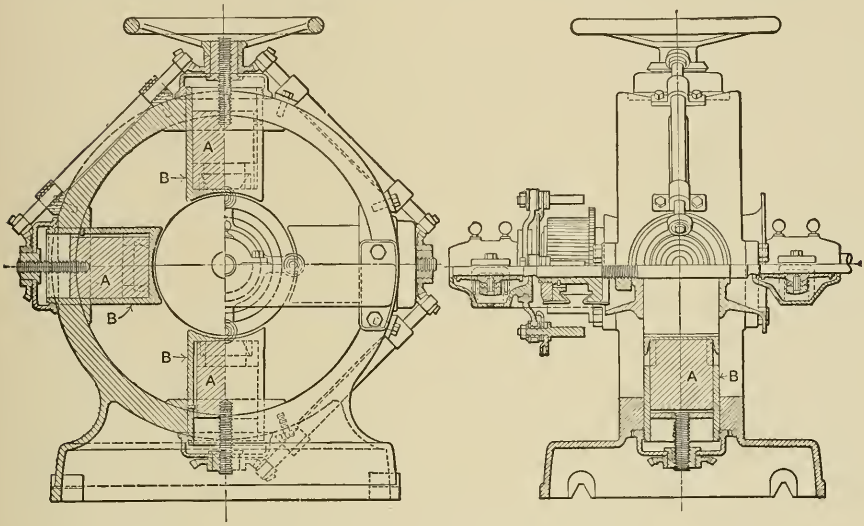


Fig. 32A. Sectional Views of Variable-Speed Motor Shown in Fig. 32.

Control by Varying Line E.M.F. This will be discussed later, under the heading *Multi-Voltage Systems.*

Combination Methods. It is evident that the preceding methods of speed control are largely independent of one another, and may therefore be used in combination, giving a wide range of speed; and several combinations are discussed in the following pages. They are applicable to shunt and series motors alike. When a number of running speeds forward and backward are required, as in hoisting machinery and machine tools, and the stops and starts are frequent, as in elevator service, the controlling apparatus must be of the most substantial construction, and is often very elaborate.

SERIES MOTORS

As with series dynamos, the armature and field windings of these machines are in series, and the same current therefore passes through both. They are always used upon electric railways, and in general for operating hoisting and mill machinery, where a strong starting torque is required without the necessity of constant speed. Like shunt motors, they are practically always operated on constant-potential circuits.

Direction of Rotation. In considering the direction of rotation of a shunt dynamo used as a motor (page 23), it was noted that the field and the direction of rotation remain unchanged when the armature current reverses its direction, and the dynamo becomes a motor; but in the case of a series dynamo used under like conditions, the reversal of the current reverses the field as well, and hence the armature tends to rotate in the opposite direction. If, therefore, a series dynamo were feeding a constant-potential circuit, and its E.M.F. fell below that of the line for any reason, its rotation would be reversed and the machine would be injured.

A series motor will run in the same direction, no matter which direction the current takes through it; for reversing the armature current reverses the field as well, and hence leaves the rotation unchanged. To reverse the rotation, it is necessary to reverse the relation of the armature and field currents, and this is usually done by interchanging the armature terminals.

Speed and Torque Curves. When a series motor running at a given speed on constant-potential mains has an additional load put upon it, the armature slows down, the counter-E.M.F. decreases, and more current flows from the line. But since this current passes through the field-coils, the field strength will increase, and this will further reduce the speed, while the torque will increase enough to take care of the increased load. Throwing off the load will allow the armature to speed up, and this will increase the counter-E.M.F., reducing the current, which in turn reduces the field strength and still further increases the speed, until the power delivered and the losses together equal the power taken from the line. Hence the series motor has a different speed for every load. If the strength of the field were proportional to the current, the speed curve would be a straight line; but as the current increases, the magnets are more nearly saturated, and the speed decreases less rapidly toward full load. The speed curve takes, in general, the form shown in Fig. 33, which is from a 50-horse-power railway motor. By having so many turns of wire on the field-magnets that they are well saturated with only a part of the full-load current, the speed variations in the neighborhood of full load are much reduced.

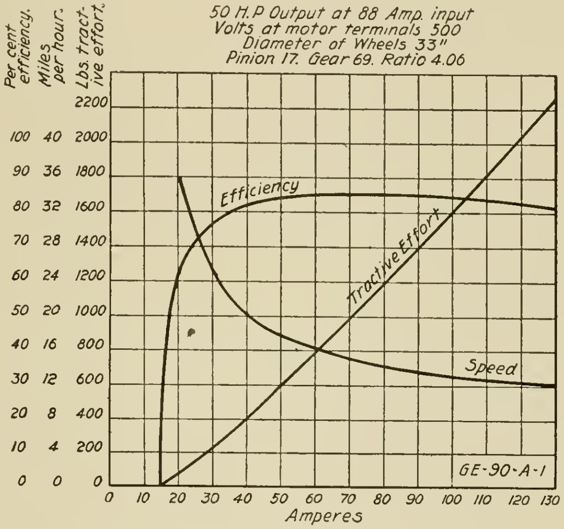


Fig. 33. Speed, Torque, and Efficiency Curves of a Railway Motor.

A valuable property of the series motor is the increase of torque in a greater ratio than the increase of current, due to the strengthening of the field at the same time. This is shown by the curve marked "Tractive Effort" in Fig. 33; for a shunt motor, this curve would be a straight line. Hence the torque of the series motor is large when starting under load, and this makes it especially valuable for railway and other service where the starting duty is severe.

When the load is removed entirely from a series motor, the diminution of the current, and consequent weakening of the field, are likely to cause excessive and often dangerous speeds, so that it is necessary to provide some safety device for cutting off the current at high speeds, unless the conditions are such that the motor cannot be wholly freed from its load, as in the case of street-cars. Very small motors, such as fan motors, are series-wound; but their normal running current is so small that they cannot take enough power from the line to injure themselves, even when running free.

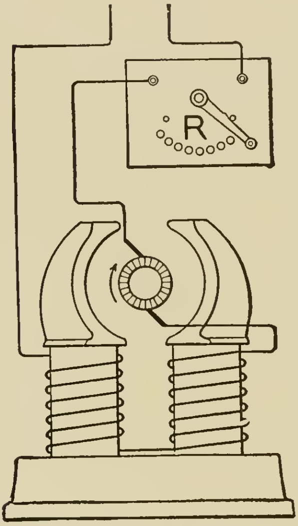


Fig. 34. Wiring Connections of a Series Motor.

Starting Rheostat. The same general principles apply to starting both shunt and series motors; but since there is only one circuit in the series motor, the wiring is simpler. The connections are as in Fig. 34, in which, however, the switch and fuses are not shown. The resistance of the field windings is always in circuit; and this, together with its highly inductive character, helps to cut down the rush of current at starting. The little magnet *E* of the automatic release (Fig. 22) is connected through a resistance across the motor terminals.

SPEED CONTROL OF SERIES MOTORS

Varying the E. M.F. at Armature Terminals. As in the case of shunt motors, all three methods of speed control are practicable, and may be used separately or in combination. With a single motor, varying the E.M.F. at the armature is most easily accomplished by a resistance in series with the motor. The connections are as in Fig. 34, where *R* may represent either a starting rheostat or a speed-controlling resistance, though of course neither piece of apparatus can be used for the purposes of the other unless specially constructed. Controlling the speed by varying the strength of the field is accomplished either by shunting the field windings so that part of the current is diverted through the shunt, or, in some cases, by short-circuiting a part of the field winding, thus reducing the effective number of turns in the coils. Motors have also been used in which the field-coils were connected in various series-parallel combinations.

Railway Motors. The most important application of the series motor is on the electric railway, the equipment being generally two motors per car. The starting rheostat is specially designed to serve as a speed-regulating resistance as well, and the various armature and field combinations are made by a controller, built like an elaborated form of that shown at *b* in Fig. 27. At starting, the controller connects both motors and a resistance in series, and the resistance is gradually cut out, leaving the motors in series across the line, each receiving one-half of the line voltage and hence running at half-speed. The next position of the controller handle shunts the field or short-circuits a part of the field winding, giving an increase in speed. Further movement of the handle removes the shunt, and connects the motors in parallel, but with a resistance in series with the pair. This is again gradually cut out until each motor receives the full line voltage across its terminals. Finally, the fields are again shunted, and the car runs at its highest speed.

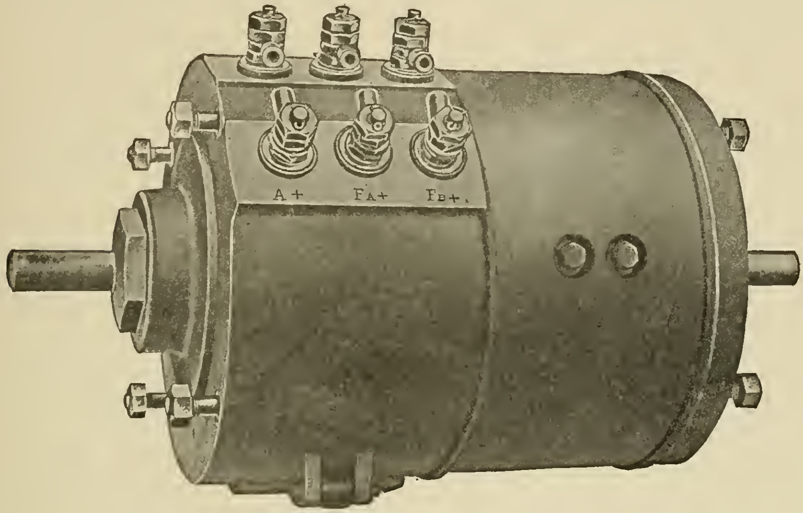


Fig. 35. Vehicle Motor.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

There are slight variations from this program, depending somewhat on the service the motors are called upon to perform. But these details of the subject of railway working are given special discussion in a separate paper.

Automobile Motors. These are series-wound, usually for operation at 40 to 80 volts, requiring 20 to 40 cells of battery respectively. A ball-bearing vehicle motor is shown in Fig. 35. The requirements for such motors are slow speed, light weight, high torque, complete mechanical protection, liberal overload capacity, and as good an efficiency as can be secured consistently with the above requirements. When two motors are used on the same vehicle, the controller may first connect the motors in series, and the halves of the battery in parallel, other changes following until the motors are in parallel across the full battery voltage, with weakened fields. No rheostat is necessary, as the voltages are low, and the total power delivered usually small.

COMPOUND MOTORS

A reversed compound dynamo becomes a differential motor. Fig. 36 represents a compound dynamo *D* supplying current to a similar machine *M* used as a motor. It is clear that the current through the series coil of the motor is reversed; and therefore opposes the magnetizing effect of the shunt current, so that the field is weaker than if the shunt were used alone. Furthermore, the motor field is progressively weakened as the armature current increases, and this tends to increase the speed; while the speed of a plain shunt motor under like conditions would decrease. Hence, by suitably designing the series winding, it is possible to obtain a motor whose speed throughout its whole range of load varies very little. This advantage was early recognized; but at the time the speed of ordinary shunt motors was sufficiently constant for most purposes, and the *differential compound motor* made little headway. For some purposes, however, particularly in the operation of textile machinery, it is very necessary to have the speed as uniform as it can be made; and the differential

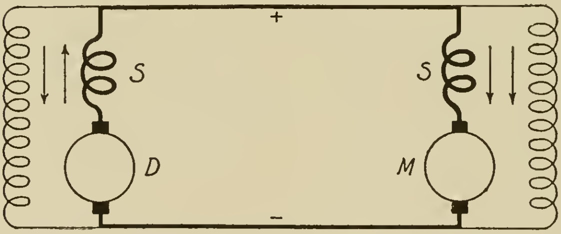


Fig. 36. Compound Dynamo Driving Compound Motor.

motor, after a period of comparative retirement, has now a wide field of usefulness.

If the current through the field is reversed, so that it assists the shunt winding instead of opposing it, the machine is called a *cumulative compound motor,* and partakes to a certain extent of the properties of both the shunt and series types, the shunt predominating. These machines are used for elevator and other service where a powerful starting torque is required, together with the general characteristics of the shunt motor. Sometimes the series field is cut out after the armature attains full speed, in which case the strong starting torque of the series motor is combined with the constant-speed property of the shunt motor.

A compound dynamo with a very strong series field will not usually run safely as a differential motor, for an overload might reduce the field so much that with the weakened torque the armature might stop entirely.

Variable-Speed Compound Motors. The success attending the the use of the *commutating pole* in generators, has led to the adoption of the same principle for motors designed for wide ranges of speed. The commutating pole is a small additional pole, placed midway between adjacent field-poles, and wound with a few turns of the series winding. Its function is to provide the necessary commutating field for the coil under the brushes, independently of the field of the main poles. Thus satisfactory commutation not only can be obtained with the brushes in a fixed position, but practically is equally good at all loads, since the strength of the pole, and hence of the commutating field, is proportional to the armature current, and this is exactly what is wanted for good commutation. Applied to motors—since commutation is practically independent of the main field—the use of the commutating pole allows the main field to be weakened much more than with the ordinary construction, and hence a much wider range of speeds is obtainable without sparking. Fig. 37 shows a motor of this type giving a speed range of 4 to 1, entirely by field control.

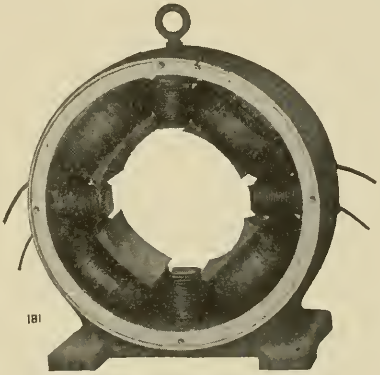


Fig. 37. Interpole Motor.
Electro-Dynamic Company, Bayonne, N. J.

MULTI-VOLTAGE SYSTEMS

When a generator is to supply only one motor, the line E.M.F. can be varied at pleasure by varying the generator E.M.F., having the generator field rheostat at the motor. This method gives any desired motor speed within a very wide range, but is obviously limited to a few special cases. The so-called *teaser* systems are in effect modifications of this principle; the E.M.F. of small motor-driven generators is added to that of the main line or subtracted from it. This particular modification of the variable line-voltage principle is useful for operating large printing presses or other machinery which must run very slowly at times under absolute control, as well as at various operating speeds.

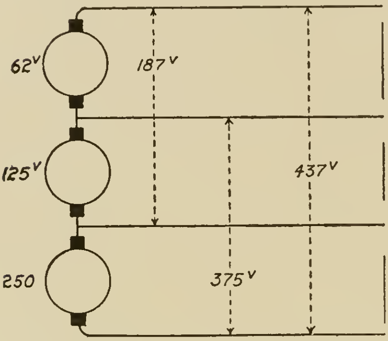


Fig. 38. H. Ward Leonard Multi-Voltage System, 1892.

The electric automobile affords an example of speed-control by varying line voltage. The batteries of the vehicle are in two sets, which are connected in parallel at starting, and then shifted to series connection at the higher speeds.

The familiar Edison three-wire system affords another illustration. In this case the fields of a 220-volt motor would be supplied from the outside wires, and the armature at either 110 or 220 volts, giving two speeds without the use of resistances.

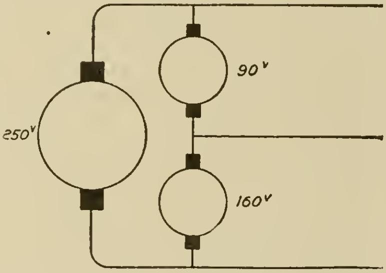
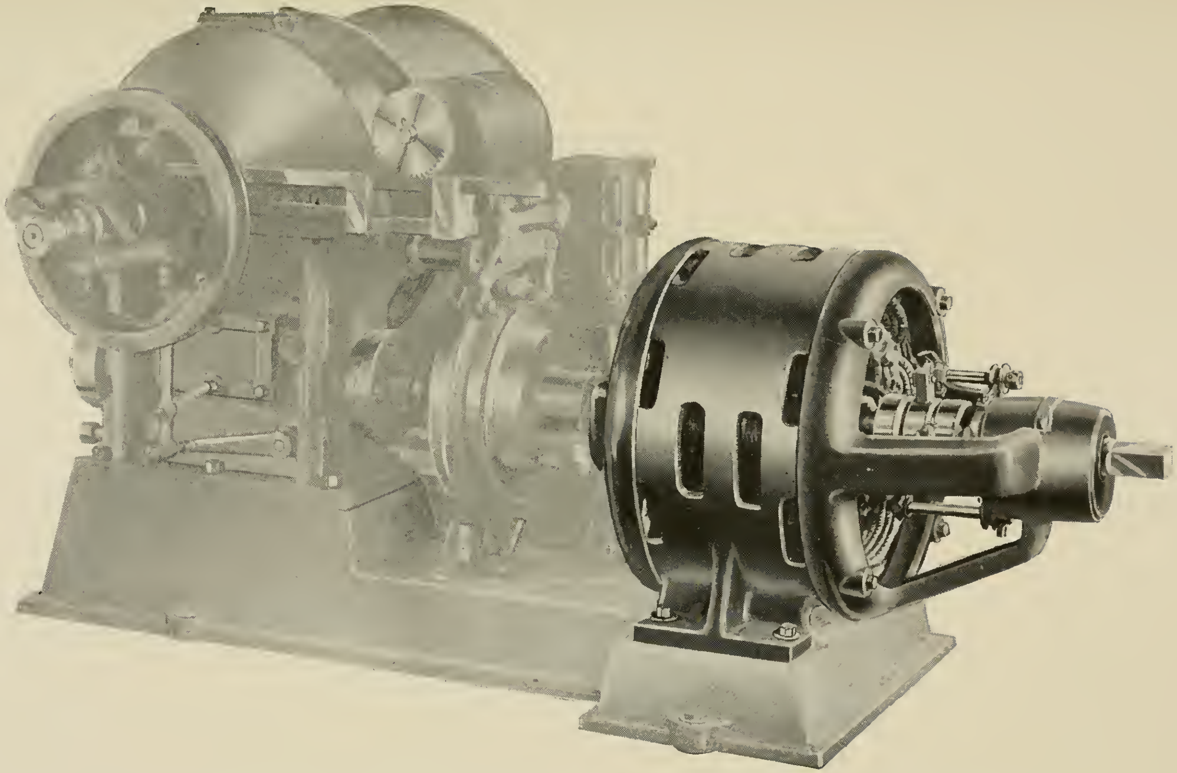


Fig. 39. Connections of Balancer Set.

By making the two sides of the system unequal in voltage, three voltages are obtained. In such a case, the lighting system of the shop, the cranes, and constant-speed motors are operated on the outside wires. A system of this kind was first brought out by Mr. H. Ward Leonard in 1892, using three generators in series and a four-wire system, obtaining the six voltages shown in Fig. 38.

The Bullock Electric Company employs a three-wire system



25-HORSEPOWER SLIP RING POLYPHASE MOTOR CONNECTED TO PASSENGER ELEVATOR

Courtesy of Richmond Electric Company

with 90 and 160 volts, and a four-wire system with 60, 80, and 110 volts, with outside voltages of 250 in both cases. The Crocker-Wheeler Company use a four-wire system with 40, 120, and 80 volts, giving 240 volts on the outside wires. Whatever voltages may be used, it is well to have at least one of the voltages *standard*—that is, 110 to 125 volts, or 220 to 250 volts, because these are standard voltages for lamps and motors.

In practice it is found that the intermediate wires carry only a small proportion of the total load, usually not over 10 per cent. This has led to the use of a single large generator and *balancers*, which are simply smaller shunt or compound dynamos with their armatures coupled together and electrically connected in series across the outside wires. The general arrangement is shown in Fig. 39, and Fig. 40 illustrates a Bullock three-wire balancer set.

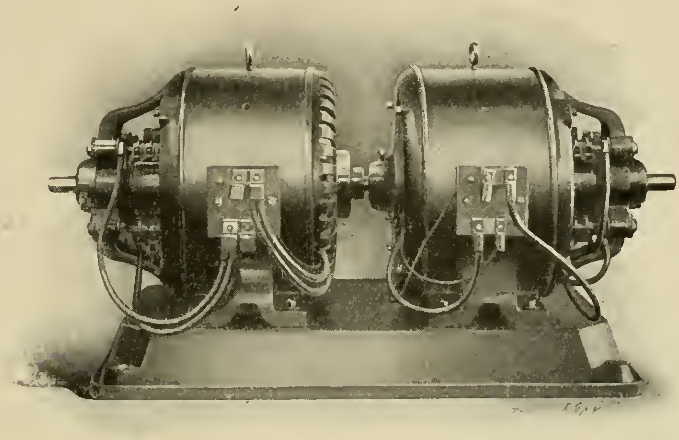


Fig. 40. Three-Wire Balancers for Bullock Multiple-Voltage System.
Allis-Chalmers Company, Milwaukee, Wis.

The action of the balancer is complex, and a full explanation is not desirable here. In general terms, however, it may be stated that when there is no current in the middle wire of a three-wire system the current through the balancer armatures is only enough to supply the running losses; but when current is drawn from either side of the system, the balancer on the other side will act as a motor, driving its companion as a generator to help furnish the required power. This is illustrated in Fig. 41, where one outer wire carries 100 amperes, the middle wire 20 amperes, and the other outer wire 80 amperes. If the balancers are equal, and there are no losses, the 20 amperes divide equally between the armatures, 10 amperes flowing downward through one as a motor to the negative main, the armature then acting as a motor driving the other machine as a generator and helping it to force the remaining 10 amperes up into the positive main again. Supposing the voltage of the main generator to be 200 volts, its output would be 90 amperes at 200 volts, or 18,000 watts. The load on the line is 80 amperes at 200 volts, and 20 amperes at 100 volts = 18,000 watts, as before.

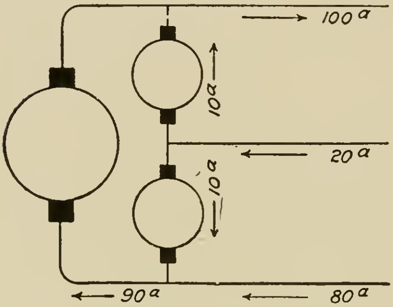


Fig. 41. Current through Balancer Set.

Of course there are always losses in the balancer armatures, so that in the arrangement shown the current through the armature acting as a motor is always greater than the current through the armature acting as a dynamo.

EXAMPLE FOR PRACTICE

If 13 amperes, instead of 10, flow through the balancer motor armature in the above example, what is the output of the main generator, and what power is delivered to the line?

Ans. 18,600 watts from the generator.
18,000 watts on the line.

This would represent 600 watts loss in the balancers, which is, however, much less than would be required to operate the second generator of an ordinary three-wire system.

The size of the balancers is determined by the maximum unbalanced load. On a three-wire system it should be large enough to operate the largest individual motor running alone on either voltage. For example, suppose we have a three-wire, 125- to 250-volt system. If a motor connected to it can develop 50 horse-power at the full voltage 250, it can develop 25 horse-power when operated on one side at 125 volts. This will require two balancers of 12½ horse-power each, since there are two machines to take care of the unbalanced current. In other words, the balancers should have 25 per cent of the capacity of the largest motor, rated at its highest voltage; and this, of course, means that the balancers may be relatively small machines.

Motors operated on this system have their fields excited from some one of the circuits, usually the one of highest voltage. The armatures are connected to either line voltage as desired, and resistances are introduced to prevent too sudden changes of current at the transition points; additional speed variations are provided by weakening the motor fields. All these connections are made upon controllers of the cylindrical type, of which Fig. 42 is a good example. It represents 20-horse-power and 40-horse-power Bullock controllers without their covers; the larger size gives 12 running speeds forward, and 9 reverse.

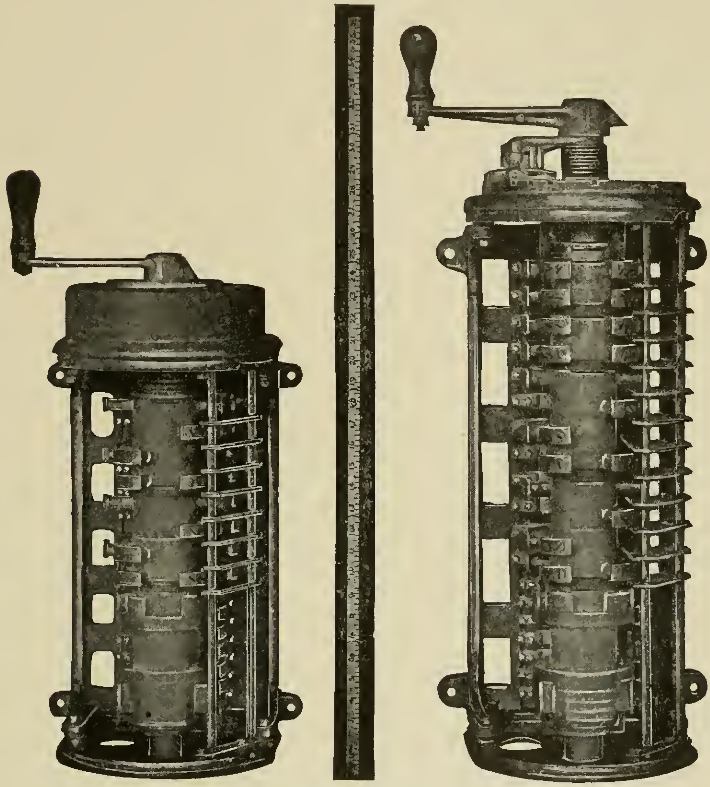


Fig. 42. Controllers Used with Bullock Multiple-Voltage System.
Allis-Chalmers Company, Milwaukee, Wis.

MECHANICAL POINTS OF MOTOR DESIGN

Motors need ample protection for the commutator and brush gear. This protection is well shown in the adjustable-speed motor illustrated in Fig. 43. This type of motor is also designed to run with the shaft vertical, in which case the lower bearing runs submerged in oil, and the upper bearing is made of anti-friction metal, running without attention. Motor end-frames or *bells* should be made so that they can be turned through 90° or 180°, to enable the machine to work with the oil wells in the proper position when mounted on a wall or ceiling. If the motor must work in a very dusty or dirty place, the ends may be protected with wire gauze covers, or even tightly enclosed with solid plates. In such cases, however, the machine has much more difficulty in dissipating heat; and for the same rise of temperature, the rating of an *enclosed* (and therefore unventilated) motor is not usually more than about half as much as if it were well ventilated. Fig. 44 shows one form of an enclosed motor. Sometimes the frames of enclosed motors are cast with projecting external ribs, to increase the cooling surface.

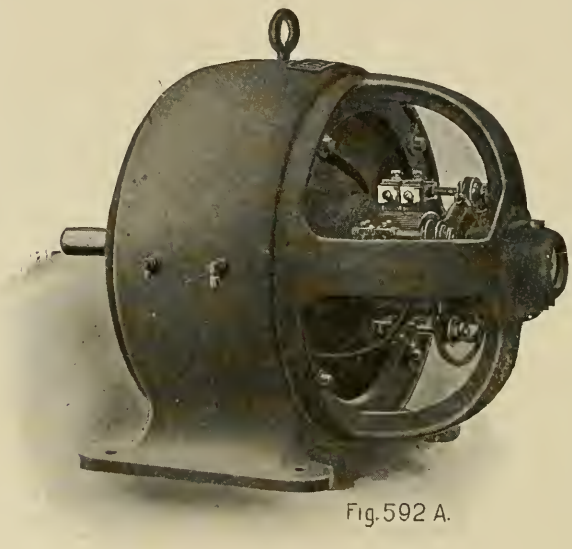


Fig. 43. Adjustable-Speed Motor.
Crocker-Wheeler Company, Ampere, N. J.

To obtain very low speeds without using a motor of disproportionately large size for its output, *back-gearing* is often used. Figs 45 and 46 give two views of a back-geared motor. To diminish wear and noise, such gears are often enclosed in cases and run in grease, like the gears of a railway motor.

Motors of large output—which, as a rule, are installed in more favorable surroundings and receive more careful handling than small motors driving individual machines—do not need special mechanical design. They are therefore built along the line of generators; and to a great extent the same parts are used for both.

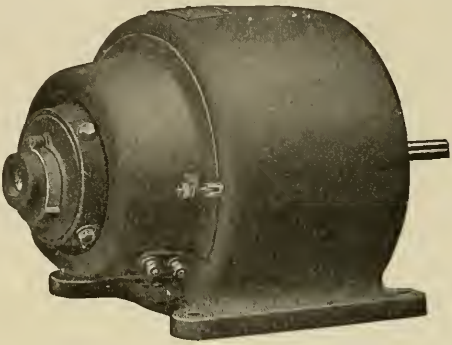


Fig. 44. Enclosed Type R Motor.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

ELECTRICAL POINTS OF MOTOR DESIGN

Since the motor is electrically identical with the dynamo, it is necessary merely to design a dynamo which will deliver the rated current at the given speed and the *counter-E.M.F.* of the motor. A single illustration will suffice. Suppose it is desired to design a 230-volt motor to deliver 10 horse-power at a speed of 825 revolutions per minute. The efficiency of such a machine should be about 85 per cent; so that the current required would be:

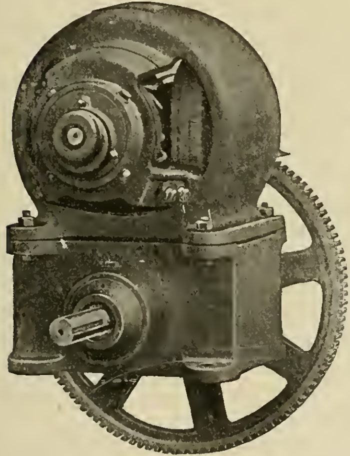


Fig. 45.

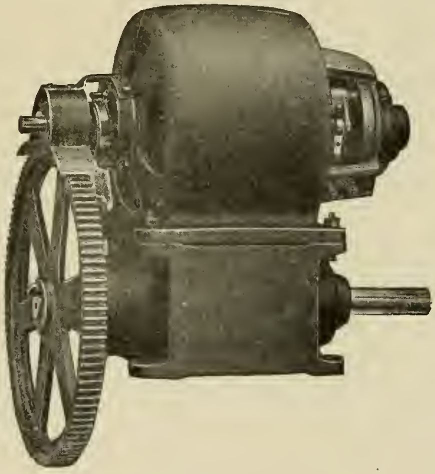


Fig. 46.

Two Views of Type R Motor with Back-Gears.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

$$\frac{7{,}460}{0.85}\text{ watts} \div 230\text{ volts} = 38.1\text{ amperes.}$$

To allow for any error in estimating the assumed efficiency, let us say, in round numbers, that a current of 40 amperes would be required. The resistance of the armature of a machine of this size and voltage will be about 0.3 ohm. Then, from the fundamental motor equation, the counter-E.M.F. can be calculated:

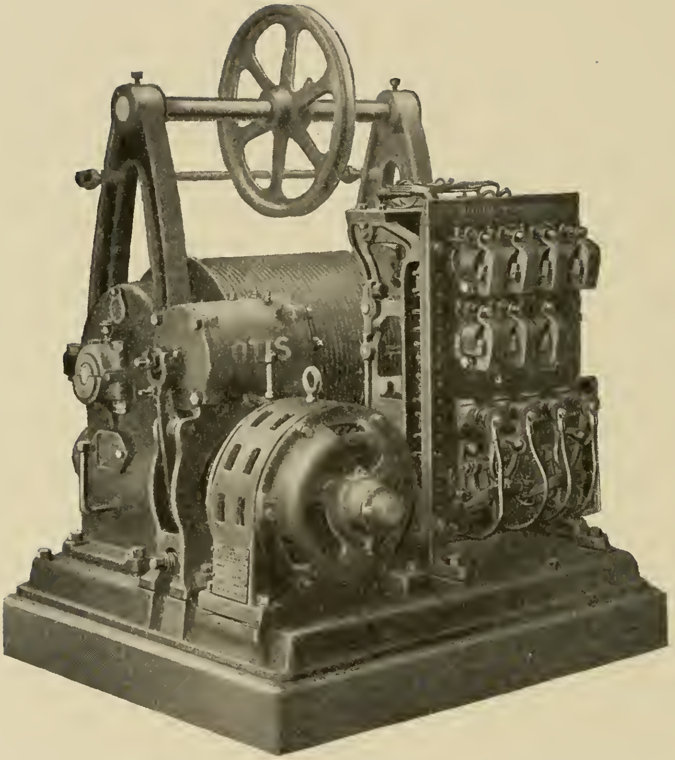
$$I = \frac{E - e}{R} = 40 = \frac{230 - e}{0.3};$$

whence,

$$e = 218\text{ volts.}$$

That is, a dynamo should be designed whose output at 825 revolutions per minute will be 40 amperes at 218 volts, and whose armature resistance is 0.3 ohm. Its field windings should be calculated for excitation at 230 volts.

For supplementary reading on the subject of the Electric Motor, the reader is referred to the following works: *Dynamo-Electric Machinery*, by F. B. Crocker, and *Electric Railways*, by J. R. Cravath (published by the American School of Correspondence, Chicago, Ill.); *Electric Motors*, by Henry M. Hobart (published by Whittaker & Co., London and New York, 1904); and a series of articles entitled "Direct-Current Motors: Their Action and Control," by F. B. Crocker and M. Arendt, published in the *Electrical World* in 1907 and 1908.



OTIS MULTIPHASE ALTERNATING-CURRENT RESIDENCE ELEVATOR MACHINE WITH FULL AUTOMATIC CONTROL

Courtesy of Otis Elevator Company

MOTOR-DRIVEN INDUSTRIAL MACHINERY

Generating Electrical Energy in Large Stations. The electric motor is now employed extensively in practically every industry where machinery is required. This widespread use of the motor has been facilitated by the improvements in its manufacture, and by the increased study and attention paid to scientific management and efficiency in large manufacturing establishments. Furthermore, generating stations, employing powerful generators and efficient prime movers, and operating with high load factor, can produce power for less per kilowatt than the smaller station operating on a much lower load factor. For this reason it is possible for the shops and manufacturing plants within the radius of the central station distribution to purchase current at a minimum cost per horsepower. By means of the high voltage transmission system and step-down transformers, power can be distributed over wide and scattered areas, thus giving the consumer of both industrial and domestic power the advantages of a great central plant and low charges, which under the direct-current system were only possible within a limited radius from the power station. The metal-working and woodworking shop, the office, the corner grocery with its electric coffee grinder, the confectionery store with its power-driven ice cream freezer, and the home with its electric fan, its washing and ironing machines, can now obtain power at any time, day or night, at minimum cost.

Motor Advantages. A careful study of the individual electric motor drive as compared with the mechanical drive clearly establishes numerous advantages for the motor, as follows:

Economy. Power is applied at the desired points in any amount at minimum loss.

Facility of Control. Motors can be started and stopped and the speed can be adjusted with the greatest possible certainty and ease.

Reliability of Service. Motors are ready for service at any moment without special preparation. They will work for any desired period at any load up to full capacity and temporarily at considerable overloads.

Flexibility of Size and Operation Requirements. The possible variety of mechanical forms is almost unlimited, and a motor can be designed with operating characteristics to comply with any requirement.

Ease of Making Measurements and Records. A complete and accurate record of operating conditions can be made, thus leading to changes for increased economy.

Increase of Production. The motor, as can be shown in the operation of the metal and woodworking industries, increases production from five to one hundred per cent for the same initial power expenditure.

Miscellaneous. The electric drive is economical in operation and maintenance, admits of better plant location, brings greater freedom from fire risks, and hence lowers the insurance rates.

These advantages are all appreciated by industrial plants, and new installations are almost always provided with individual or group motor systems. The only reason why the adoption of the individual motor has not been universal is the expense of changing from a going shop by the old countershafting method to the new and more economical motor drive. In changing a shop over to motor drive, the student must keep in mind that all conditions affecting the shop must be carefully studied. He must study the character of the product turned out and make sketches of different layouts showing the arrangement of the machines for the best routing of material. The cost of the individual drive must be compared with that of the group drive and, in the latter case, care must be taken to group the proper machines under one jack shaft so as not to interfere with the progression of the material from one machine to another. Keep in mind the advantages and disadvantages of the two drives. Provide plenty of aisle space and distance between machines so that the material will not crowd the machine and hinder the machine operator. See that motors are placed in accessible places and that all switches, circuit breakers, and fuses are enclosed in fireproof boxes. If direct-current motors are used, see that they are of the enclosed type.

A discussion of the development of the motor drive in the various industries where it has been most completely exploited, will give the reader a very good idea of its far-reaching effects.

METAL-WORKING MACHINERY

The past few years have witnessed a decided improvement in the art of cutting metals, due chiefly to the prevalent use of high-speed tool steel, and the accurate analysis of cutting speeds for different materials, coupled with the adoption of Mr. Taylor's methods of tool design, and the heat treatment of tool steel.

For a shop to obtain maximum production, the machine power must be adequate for a constant full load on the machine tool, must be sufficient to cope with temporary overloads, and at the same time must be capable of instant speed adjustment by the machine operator. The electric motor, direct-connected to the machine tool by gears, silent chain, or short belt, has shown that it is the best drive for all requirements. It is fast superseding all other power for this class of work.

Methods of Driving Machines. There are two drives in general use for transmitting power from the electric motor to the machine tool: (1) the individual drive, which requires a motor for each machine coupled to it by gears, silent chain, or short leather belt; and (2) the group drive, consisting of one motor driving several machines through a short shaft, pulleys, and belts, Fig. 1.

Choice of Drive. While best modern practice recommends the individual drive for all machines, there are conditions in service where the group drive is more economical. The choice of drive for any particular shop will depend upon the manufacturing requirements of the shop, kinds and position of machines, the age of the machinery, and the resources of the company.

Where the power required for a given machine or group of machines is variable, or where high intermittent loads are coming on the machines at periods, it is found that the group drive will give a wider margin to carry over the heavy peak loads. In many shops with old equipment the large first cost of motors and wiring for each machine is not warranted, and here the group drive would be recommended because of its lower cost for wiring and motors. For example, if an engine is to be displaced, the long lines of shafting can not, as a rule, be economically discarded in many shops. Therefore, it would be better to cut the main line shaft into short lengths and drive each length by a single motor. In this case the jack shaft should not be larger than can be supported by three shaft hangers; in fact, a considerable economy can often be effected by replacing the old shafting with lighter material. In many of the minor shops for railroad division points, the group drive is used for small machines, and the individual drive only for large wheel lathes or for machines at a distance from the main shop or drive.

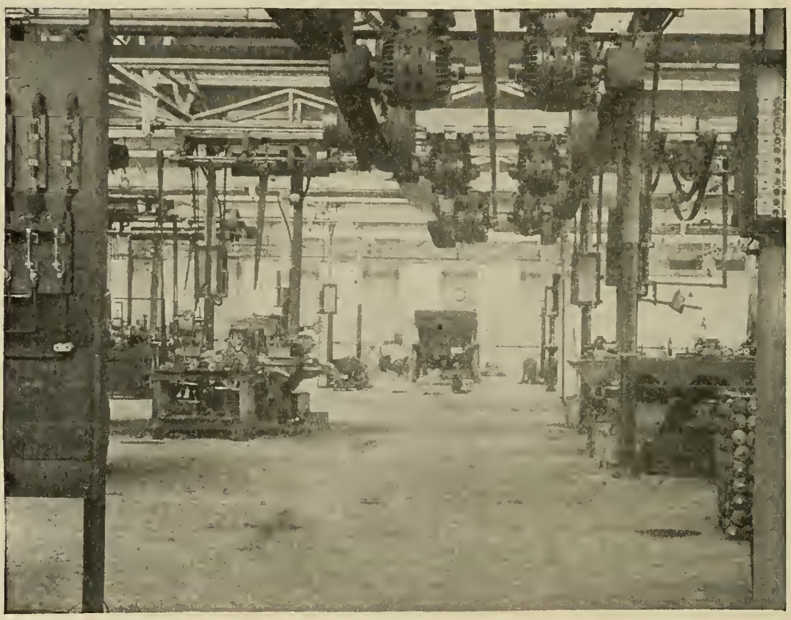


Fig. 1. Characteristic Group-Drive Installation
Courtesy of Fairbanks, Morse & Company

Choice of Motor. In specifying the proper operating speed for most economical production, machine tools may be considered in two classes: (1) constant-speed tools, represented by reciprocating machine tools such as planers, presses, punches, slotters, shapers, gear and bolt cutters; and (2) adjustable-speed tools, such as lathes, and boring, drilling, and milling machines.

Direct-current motors may be used for either constant- or adjustable-speed service, and hence they are applicable to either class of tools. Alternating-current motors are essentially constant-speed machines, but can be used to drive adjustable-speed machine

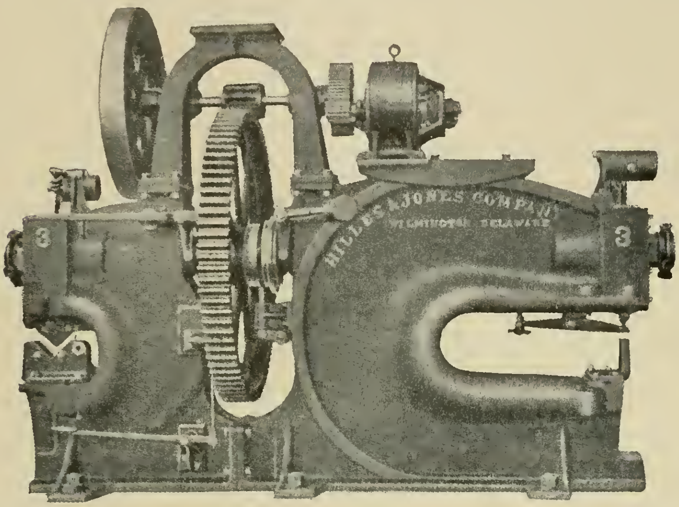


Fig. 2. Westinghouse Motor Driving Hilles & Jones Heavy Punch and Shear

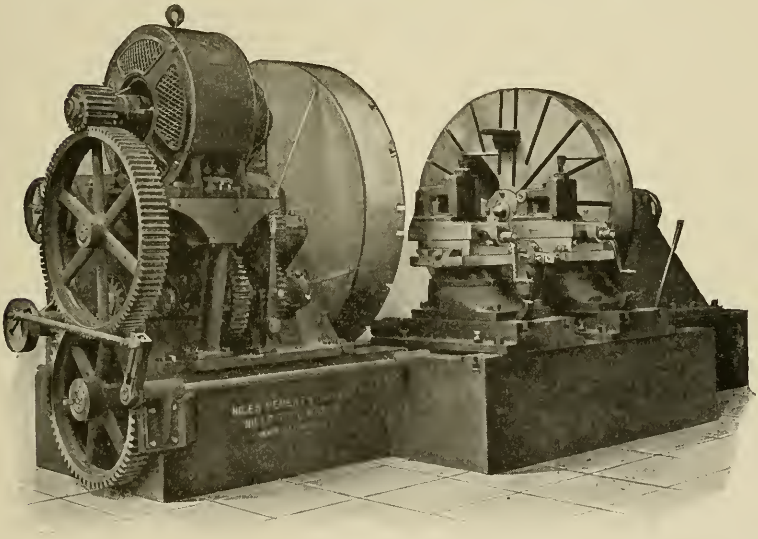


Fig. 3. Westinghouse Motor-Driving a Niles Driving-Wheel Lathe
Courtesy of Westinghouse Electric and Manufacturing Company

tools by means of gear boxes or other mechanical speed-changing devices. This arrangement, however, does not give as fine speed gradations as can be obtained by adjustable-speed direct-current machines.

Power Required for Electric Drives. The actual power required to drive any given machine can be determined accurately only by connecting up a temporary motor to the machine or jack shaft and measuring the horsepower input by wattmeters in circuit with the motor. A less accurate but more usual method is to refer to catalogues of manufacturers for authentic data regarding similar machines. In the Appendix, Table I, will be found a quantity of data as recommended by the Westinghouse Electric and Manufacturing

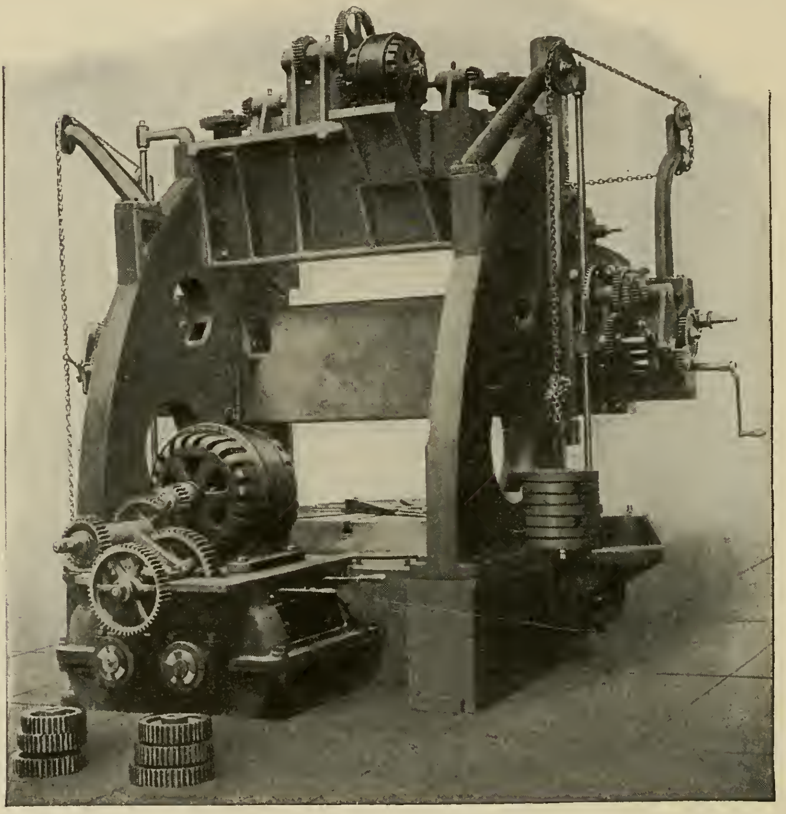


Fig. 4. Motor-Driven Niles Vertical Boring Mill
Courtesy of Westinghouse Electric and Manufacturing Company

Company, giving the motor horsepower required to drive a number of different metal-cutting machines. The table is based on average practice, and the estimated horsepower in any case may be decreased for light work or increased for very heavy work.

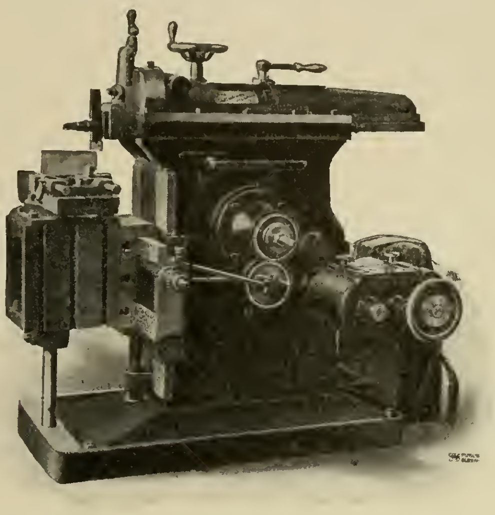


Fig. 5. Cincinnati Milling Machine Company Shaper Driven by Induction Motor
Courtesy of General Electric Company

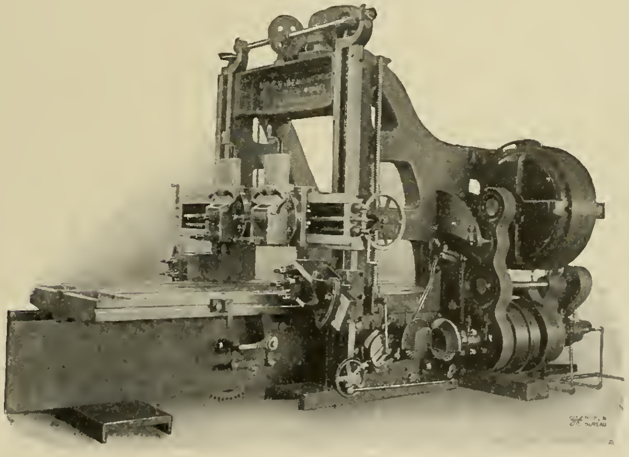


Fig. 6. General Electric Induction Motor Driving Niles-Bement-Pond Planer
Courtesy of General Electric Company

Motor Applications. A few typical examples of the connection of the motor to the machine tool are here given to illustrate the general practice. Fig. 2 shows a Westinghouse Type S varying-speed motor geared to a Hilles and Jones No. 3 heavy punch and shear. This punch requires a 15-horsepower motor at 1000 r. p. m. In Fig. 3, the motor is connected to a Niles 90-inch driving wheel lathe, the motor being a 50-horsepower adjustable-speed Type S motor. Fig. 4 shows a 15-horsepower Westinghouse motor and a 3-horsepower motor connected to a Niles 10-foot vertical boring mill. The 15-horsepower motor drives the bed plate and the 3-horsepower motor placed on top of the frame is used to raise the rail. Fig. 5 is an example of the application of a constant-speed induction motor to a shaper, the adjustable speed being obtained at the shaper head by a mechanical gear change. This is a 15-inch Cincinnati shaper, driven by a General Electric 3-horsepower 1800-r. p. m.

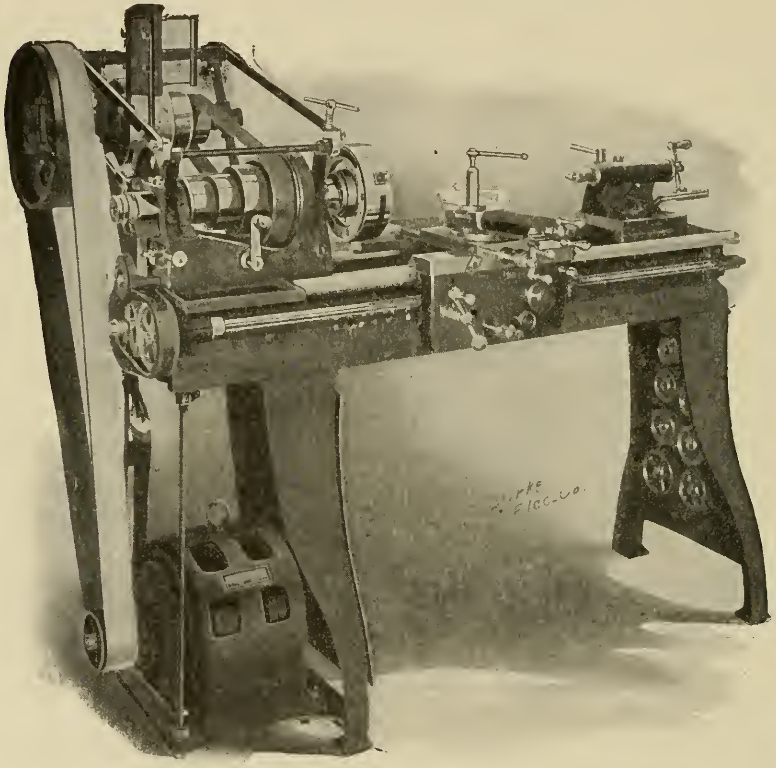
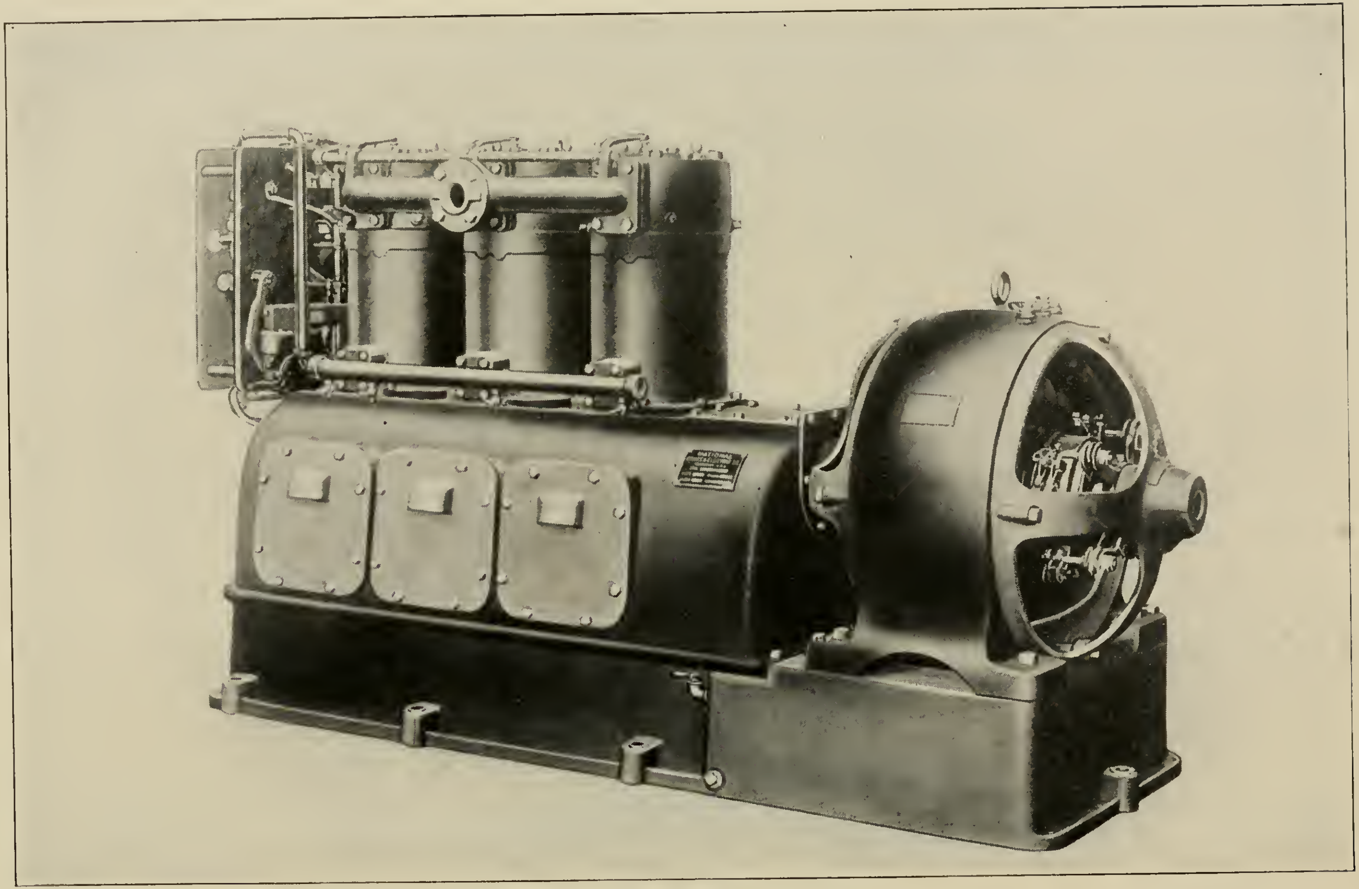


Fig. 7. Individual Motor Drive Connected to Lathe
Courtesy of Burke Electric Company



NATIONAL AIR COMPRESSOR WITH DIRECT-CURRENT MOTOR AND COMBINED AUTOMATIC CONTROLLING DEVICE

Courtesy of National Brake and Electric Company induction motor. In Fig. 6 is shown a General Electric induction motor directly connected to a planer.

In many instances it is found desirable to apply the electric drive to machines originally designed for the overhead mechanical drive. In Figs. 7 and 8 are two coupling arrangements by the Burke method. The upper cone pulley rests on pipe brackets, a method which makes it possible to change from the mechanical to the individual motor drive in a short time.

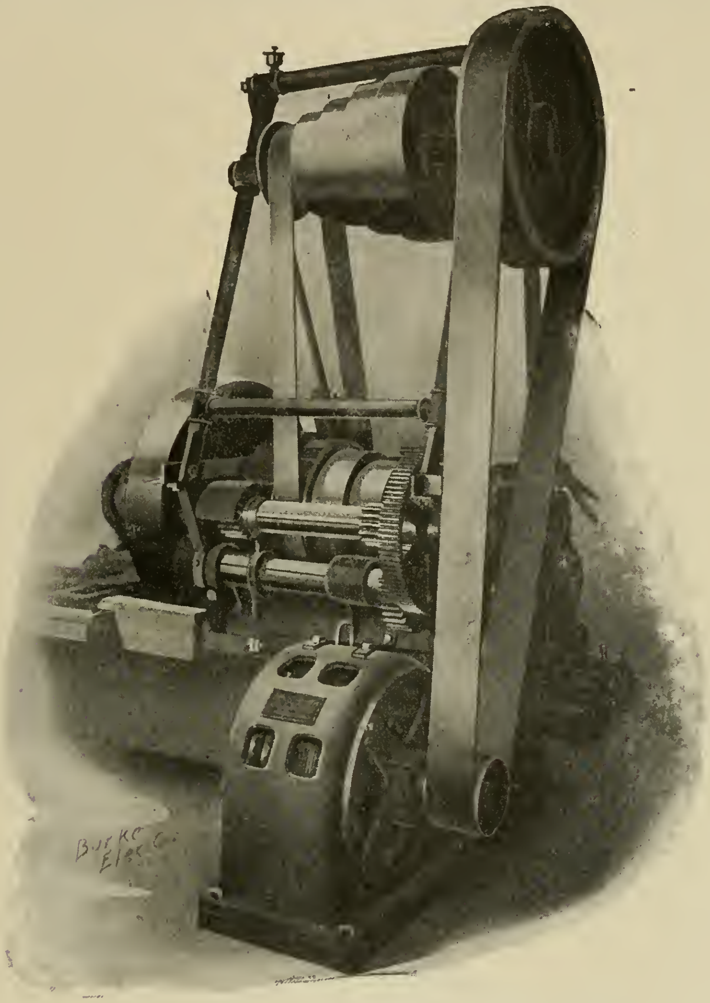


Fig. 8. Belted Motor Drive Showing Countershaft Support
Courtesy of Burke Electric Company

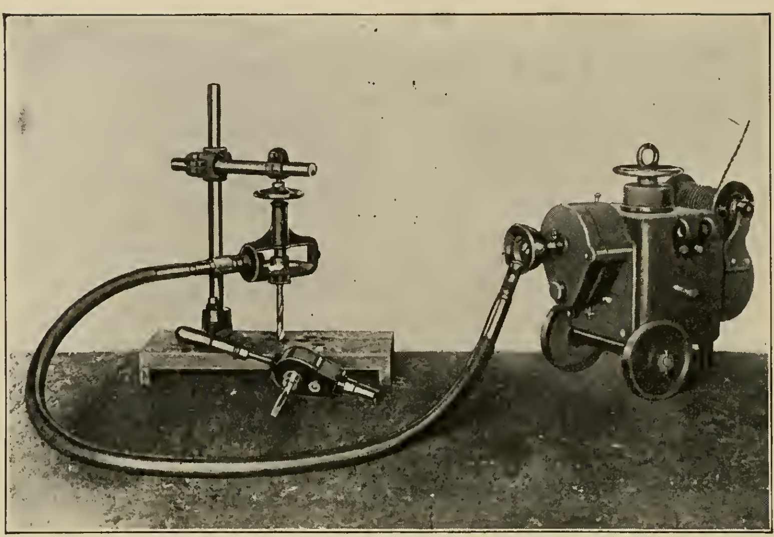


Fig. 9. Stow Multispeed Motor Driving Small Drill Through Flexible Shaft
Courtesy of Stow Manufacturing Company

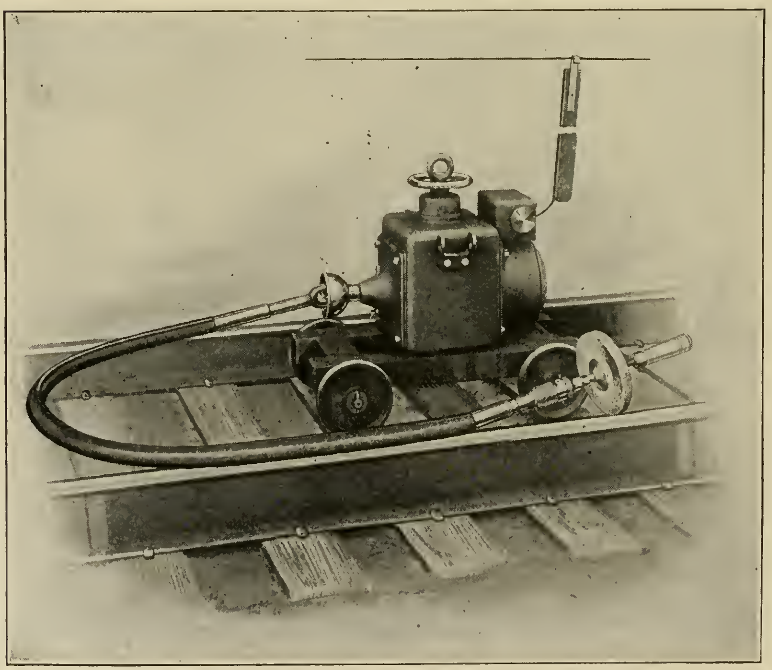


Fig. 10. Stow Multispeed Motor with Flexible Shaft and Rail Grinder
Courtesy of Stow Manufacturing Company

Figs. 9, 10, and 11 show applications of the Stow Multispeed motor and Stow flexible shaft to portable drills, grinders and buffers.

WOODWORKING MACHINERY

Advantages of Electric Drive. In a woodworking plant using a mechanical drive, there is constant danger from fire due to the close proximity of the boiler room to the wood, sawdust, and varnish rooms. The insurance rate for a hazard of this kind is, therefore, correspondingly high, often reading as high as 8 per cent. This rate may readily be reduced to 1 per cent by installing the electric drive.

Again, the shafting, which, in the case of the mechanical drive, is suspended from overhead beams and columns, can be dispensed with if the individual drive is substituted, thus saving about 5 per cent on the cost of the building, since the framework can be made of lighter construction. This 5 per cent saving in cost of construction will in many cases pay a large portion of the cost of electrical equipment.

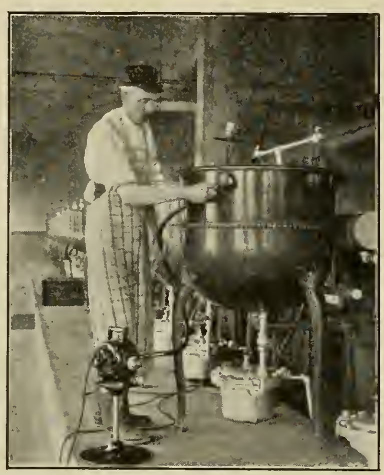


Fig. 11. Stow Manufacturing Company Buffing Equipment

Choice of Motor. Alternating-current squirrel-cage constant-speed motors are the most suitable drive for the majority of woodworking machines, although in some few machines—as in "hogs" for reducing slabs to kindling—a high flywheel effect makes starting difficult, and phase-wound motors with external resistance are preferable. For machines requiring adjustable speed, such as certain types of wood lathes, direct-current shunt-wound motors give the best results because of the greater range of speeds.

Individual and Group Drive. Although the best and most economical practice requires that all machines be equipped with individual motor drive, there are many cases in the average shop where the group drive is more economical. This is true for machines used frequently but not simultaneously. Thus, an emery wheel, knife grinder, carving machine, cabinet saw, and disk sander may all be run by one motor with considerably less capacity than the aggregate ratings of the motors necessary for the individual machines.

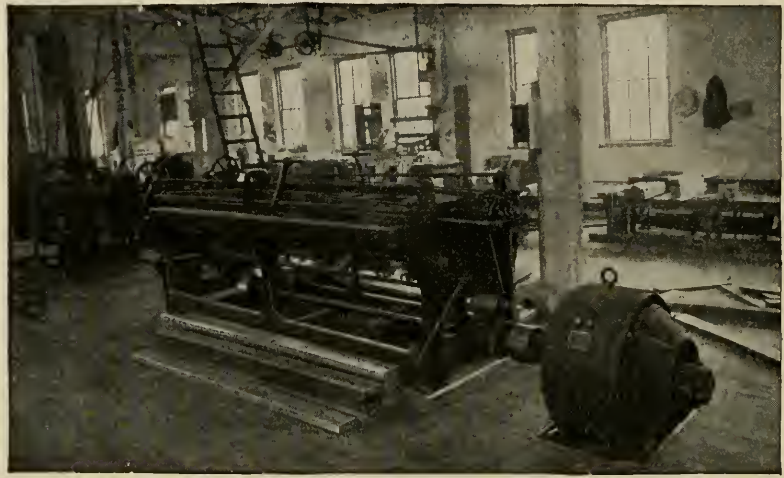


Fig. 12. Westinghouse Motor Direct-Connected to Hays Spindle Borer
Courtesy of Westinghouse Electric and Manufacturing Company

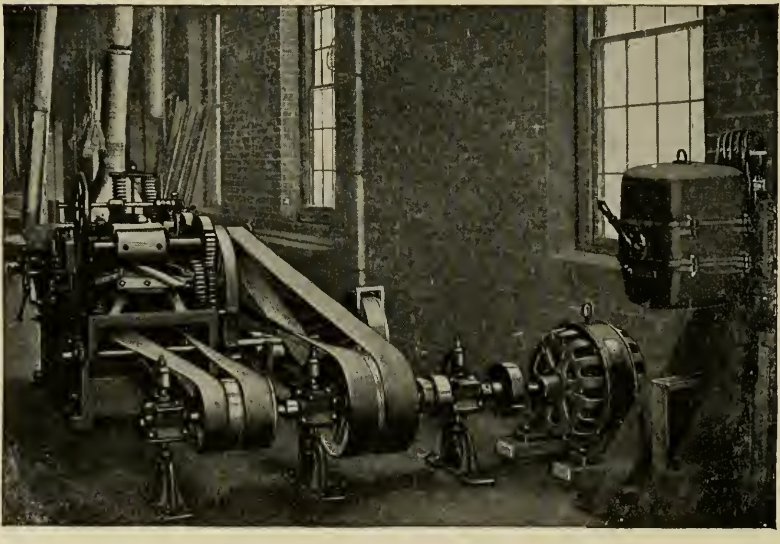


Fig. 13. Induction Motor Driving a Berlin Open Side Molder
Courtesy of Westinghouse Electric and Manufacturing Company

Power Required. The power required to operate any machine may be obtained from tests as explained under metal-working machinery or from manufacturers' catalogues. The data obtained from the manufacturers is reliable and should, in every case, include the horsepower required for the machine running light as well as loaded. In most woodworking machines there is a large friction factor, the power required to run the machine without load being often as high as 50 per cent of full load.

Motor Applications. In Fig. 12 is shown a Westinghouse 10-horsepower direct-current motor driving an E. B. Hays 24-bit spindle borer; as shown in the figure, the motor is coupled to the countershaft by means of a flange coupling. Fig. 13 shows a first-class installation and one that can be installed in a short time. A 20-horsepower Westinghouse induction motor is coupled to the jack shaft by means of a flange coupling. The machine shown is a Berlin No. 108 10-inch open side molder and requires 9 horsepower, running light; 15 horsepower is the average rating at full load, feeding 85 feet per minute. Thus over 50 per cent of the power is lost in machine friction alone.

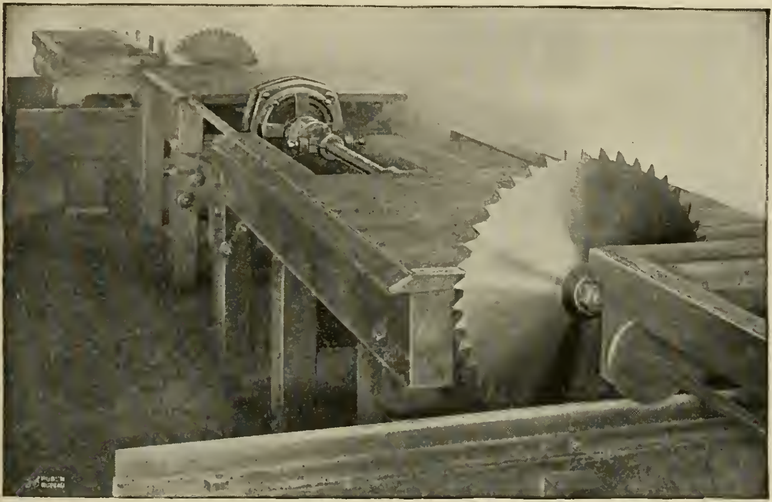


Fig. 14. Induction Motor Direct-Connected to Two Circular Cross-Cut Saws
Courtesy of General Electric Company

In Fig. 14 is an illustration of the application of the individual drive—a 7½-horsepower 1800-r. p. m. General Electric induction motor, direct-coupled to two 20-inch circular cut-off saws.

Fig. 15 shows a 5-horsepower 1800-r. p. m. General Electric induction motor driving a 12-inch ripsaw—a very compact arrangement of motor and machine. The induction motor is especially recommended in woodworking shops, because of the presence of inflammable materials. The motor as shown is covered with sawdust which would require only a spark from an exposed direct-current motor to ignite. But sawdust is perfectly harmless surrounding the induction motor.

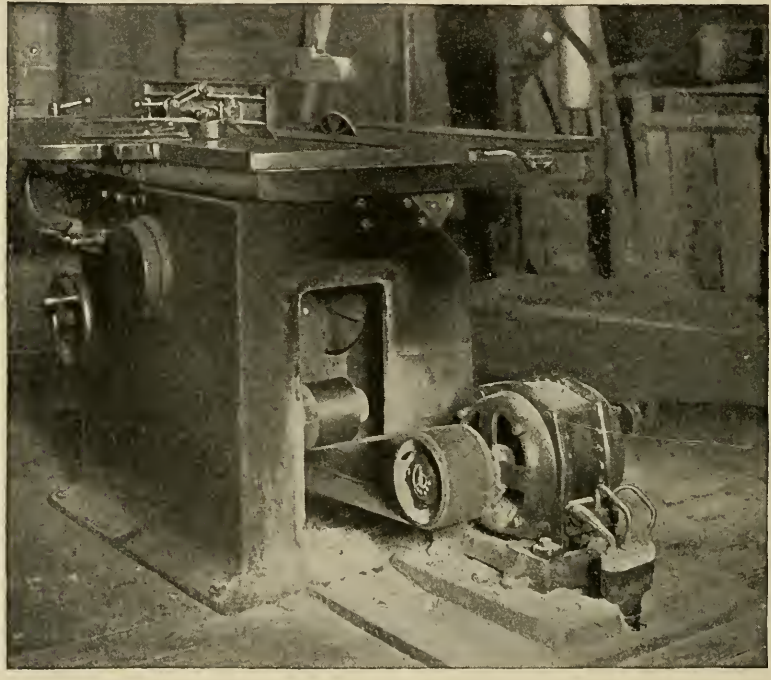


Fig. 15. Induction Motor Driving a Ripsaw
Courtesy of General Electric Company

Fig. 16 shows a 15-horsepower Westinghouse induction motor driving a 42-inch Berlin 3-roll sander.

Fig. 17 is a very good illustration of a neat and compact installation of a 30-horsepower Westinghouse induction motor, direct-connected to a Sterling 30-inch double blower, used to collect sawdust and shavings.

In Fig. 18 is shown a floor scraper and polisher manufactured by the American Floor Surfacing Machine Company. The motor is mounted on top of the bed of the machine and is belted to the driving pulley. The machine is moved forward or backward by its own

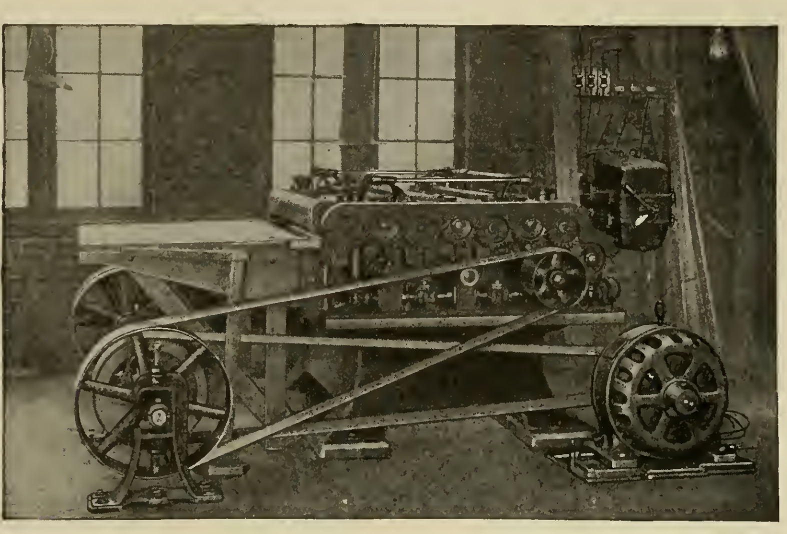


Fig. 16. Induction Motor Belted to Berlin Sander
Courtesy of Westinghouse Electric and Manufacturing Company

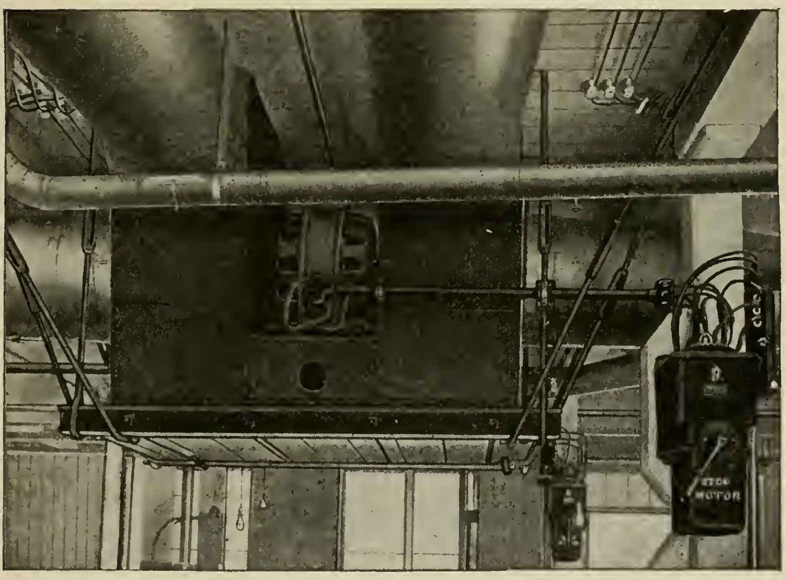


Fig. 17. Induction Motor Direct-Connected to a Double Blower
Courtesy of Westinghouse Electric and Manufacturing Company

power at the rate of 35 feet per minute. It has two rolls 9½ inches by 18 inches, covered with sandpaper, driven 600 r. p. m., all operated by the motor through belt drives.

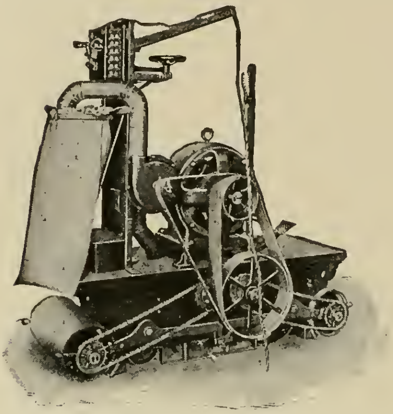


Fig. 18. Floor Scraper and Polisher with Individual Motor Drive
Courtesy of American Floor Surfacing Machine Company

PRINTING PLANTS

The electric drive has been found easily adaptable to printing plants, not only to those of the large daily newspapers and publishing houses but also to the little out-of-the-way job printing office. Its many advantages of increased production, better light, hygienic surroundings, and minimum floor spaces, all contribute to a higher efficiency. A few years ago it was thought that any old garret or shack was good enough for the printer. Cleanliness was practically impossible with the inevitable flapping greasy belts. Today the briefest inspection of a scientifically managed printing plant shows the effects of improved working conditions. Better light and ventilation can be obtained and the personal injury hazard is reduced enormously, by eliminating belts, shafts, and pulleys. This is especially true in the case of large plants employing women. Figs. 19 and 20 picture the transformation which may be brought about by the adoption of the motor drive.

Motors. The motor recommended for any particular press will depend upon the speed regulation demanded. For most presses, the constant-speed motor is required, preferably of the direct-current compound-wound type. Armature control is used only in starting and in turning the press at a very low speed while getting it ready for the run. In color work, where a varying speed is required, an adjustable-speed motor should be used. The best design in any case for the flat-bed rotary, or stop cylinder, press is a compound-wound adjustable-speed motor, while a constant-speed motor is suitable on small job presses.

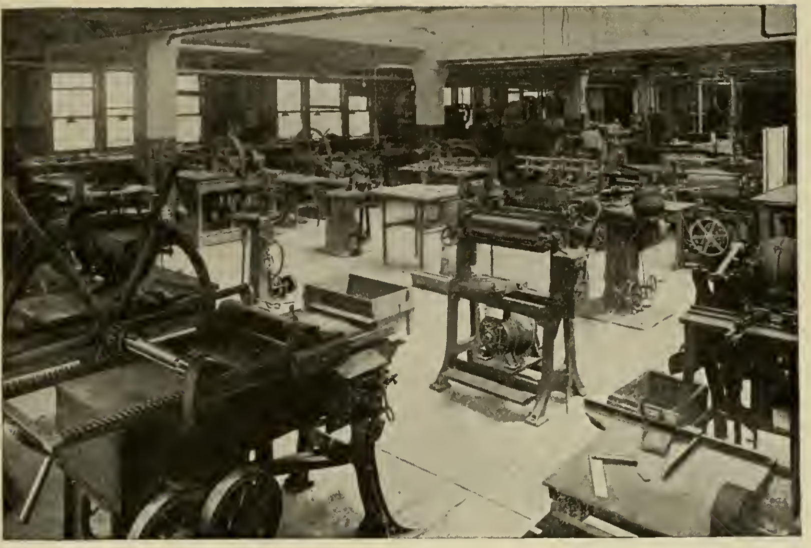


Fig. 19. Electrotyping Plant Equipped with Sprague Motors
Courtesy of Sprague Electric Works

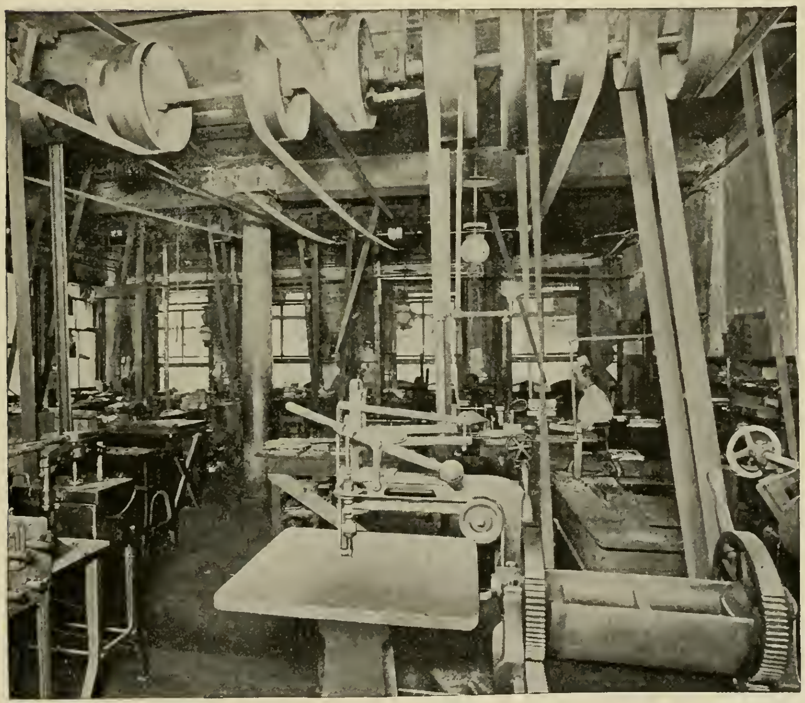


Fig. 20. Old Style Electrotyping Plant with Overhead Shafting and Belt
Courtesy of Sprague Electric Works

Motor Applications. In Fig. 21 a Sprague Electric round type motor is shown connected up through a belt drive to a Simplex machine.

Figs. 22 and 23 show, respectively, a geared and belted transmission to a rotary press. Fig. 24 shows the ease with which the electric drive can be applied to a bank of linotype machines. The motor is simply bolted to the floor directly in front of the machine and belted to the main drive pulley. Fig. 25 shows a back-geared motor coupled to a Fuchs and Lang litho. stone grinder.

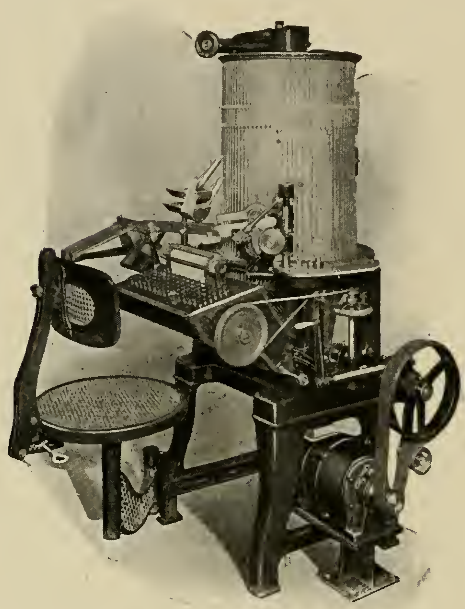


Fig. 21. Motor Operating Simplex Machine
Courtesy of Sprague Electric Works

LAUNDRY WORK

The essential feature in every laundry is cleanliness, and belts and shafting make the dirt problem a serious one. If the most scrupulous cleanliness is not preserved, the work will become soiled as it passes through the various processes, thus necessitating sending it back to the washer and again through the complete cycle of operations. This will mean not only unsatisfactory work but a decrease in the output of the plant. Besidse this disadvantage of the mechanical drive, there are the ever-present problems of light, ventilation, and loss of power in long shaft drives. Actual tests have shown that a saving in operating expenses of as high as 30 per cent has been effected where the electrical drive was substituted for the mechanical method.

Motor Applications. In Fig. 26 is shown a Crocker-Wheeler "Form L" motor geared to a starcher. The motor rests on a platform which is bolted to the frame of the starcher. The same type of driver may be applied to washing machines, ironing machines, etc.

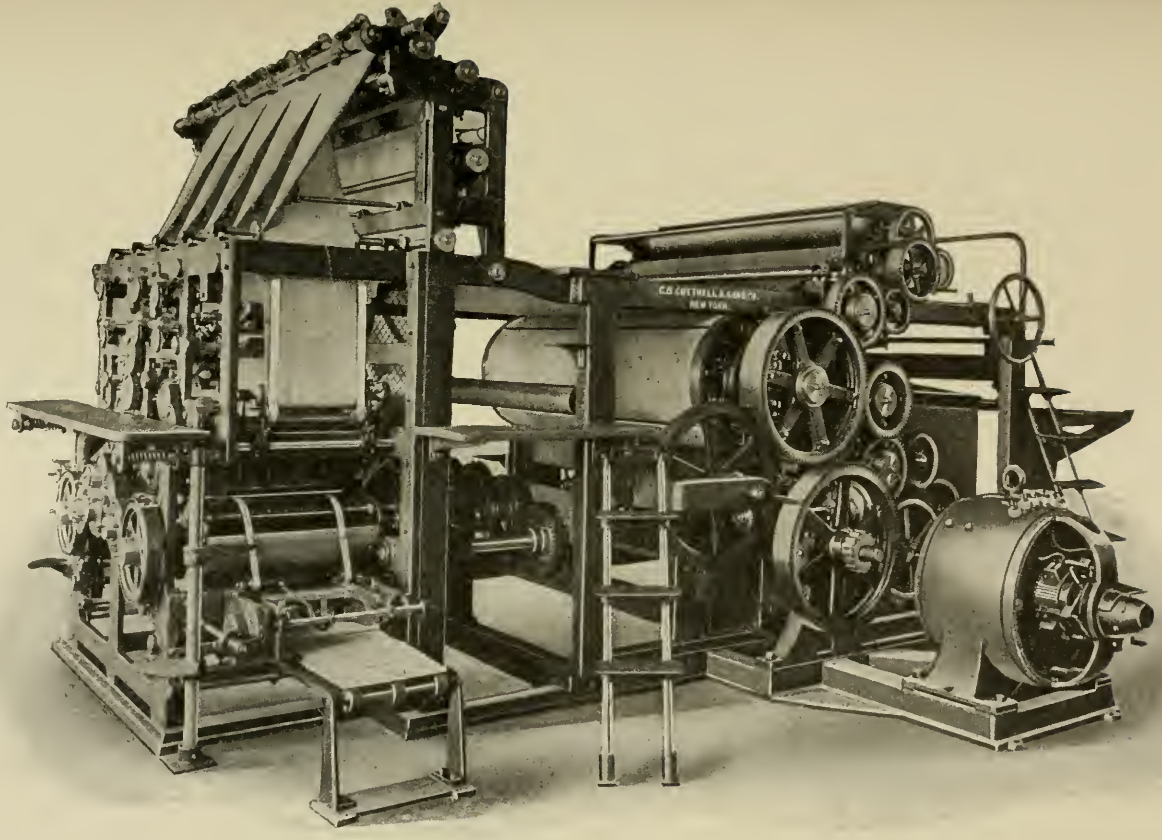


Fig. 22. Sprague Motor Geared to a Cottrell Rotary Magazine Press
Courtesy of Sprague Electric Works

POWER FOR PULP MILLS

The adoption of the electric drive in the pulp mill has been extensive since uninterrupted service has been guaranteed by commercial power plants. A definite saving in the cost of production can be effected because the power developed is applied to the work without any large losses in transmission.

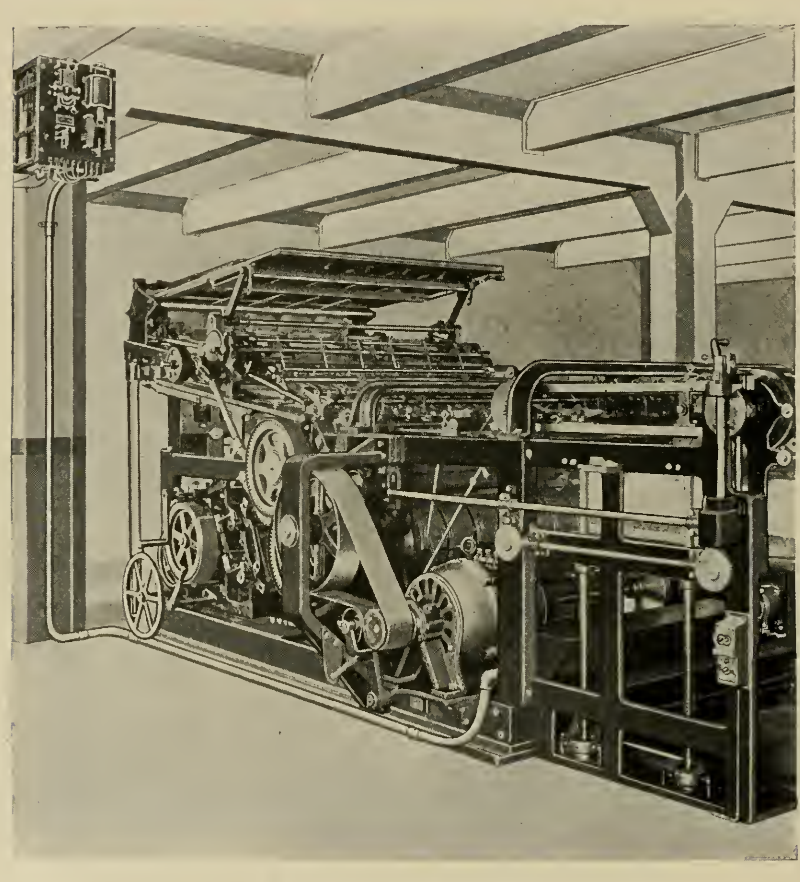


Fig. 23. Sprague Motor Belted to a Cottrell Rotary Printing Press
Courtesy of Sprague Electric Works

Motor Types. In the pulp mill both alternating- and direct-current motors can be used. A large percentage of the machines operate at constant speed and, as the alternating-current induction motor is designed primarily for constant speed, it should be chosen in preference to the direct-current motor. Where a wide variation in speed is required, as in the finishing end of a paper machine, the direct-current motor should be used.

Applications. Fig. 27 shows a well-designed installation of a 300-horsepower General Electric induction motor direct-connected to a grinder. In Fig. 28 a 150-horsepower induction motor is driving two beaters through silent chains.

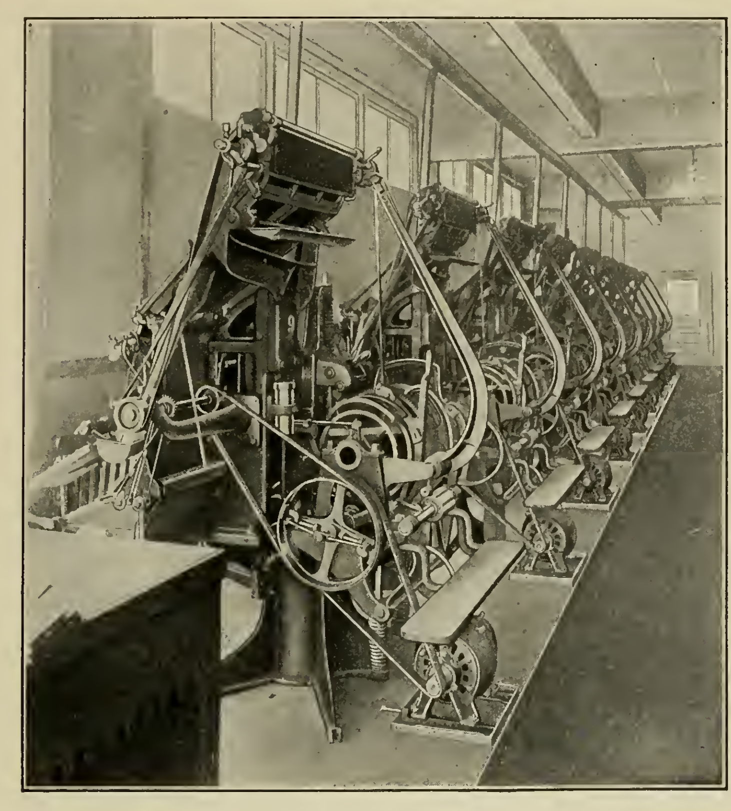


Fig. 24. Bank of Linotypes Equipped with Individual Motor Drive
Courtesy of Sprague Electric Works

SHOE AND LEATHER INDUSTRY

Rapid progress has been made in the shoe and leather industry in the past few years, chiefly because of the improvement made in the machinery used in the various manufacturing processes. Formerly hides were prepared and shoes were made completely by hand. Today, of the ninety operations on each pair of shoes, seventy are performed by machinery. The machines used are chiefly of small power, requiring a maximum of about 2½ horsepower for the large sole-cutting machines and less than one-tenth of a horsepower for many of the smaller machines.

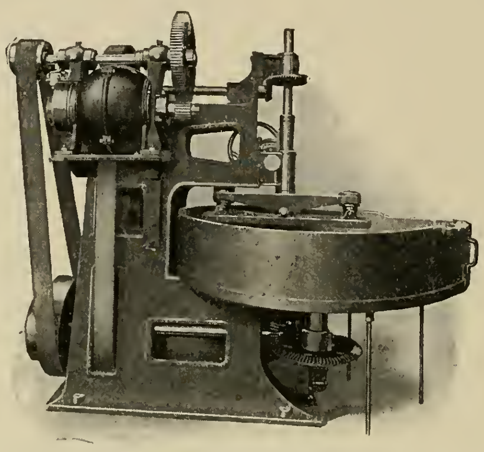


Fig. 25. Fuchs and Lang Lithographers' Stone Grinder Equipped with Motor Drive
Courtesy of Sprague Electric Works

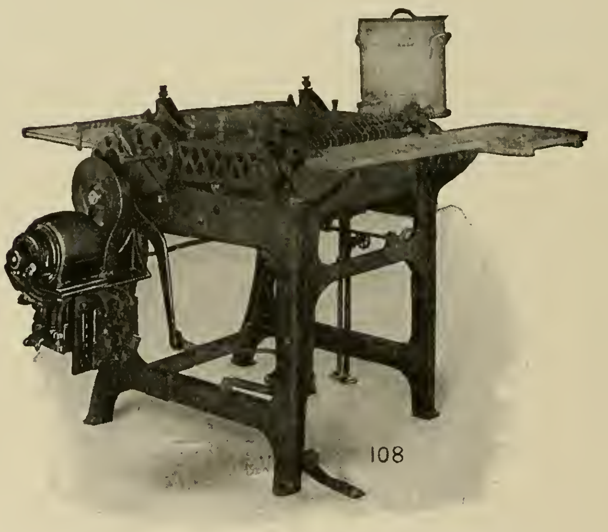


Fig. 26. Crocker-Wheeler Motor Geared to a Starcher
Courtesy of Crocker-Wheeler Company

Type of Drive. The electric motor drive has become an important factor in this industry because of its ability to maintain the

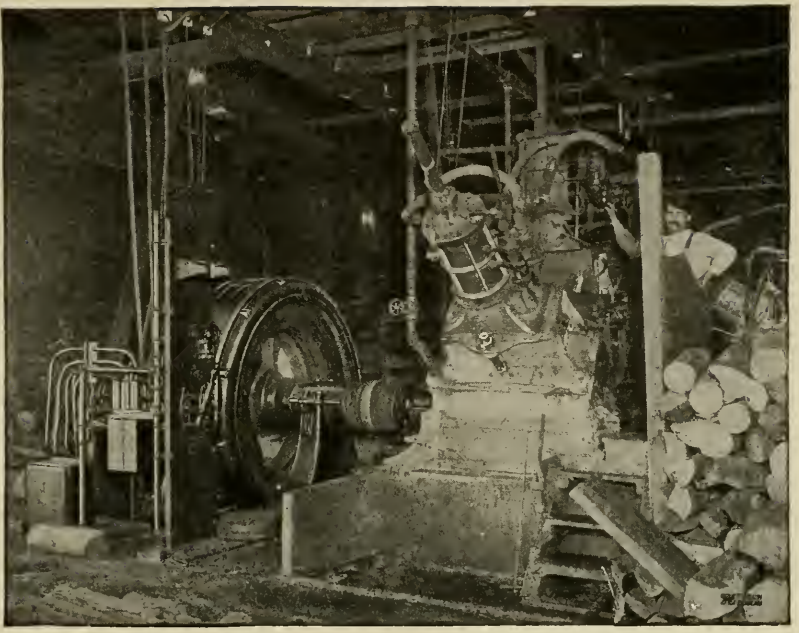


Fig. 27. 300 H. P. Motor Direct-Connected to a Grinder
Courtesy of General Electric Company

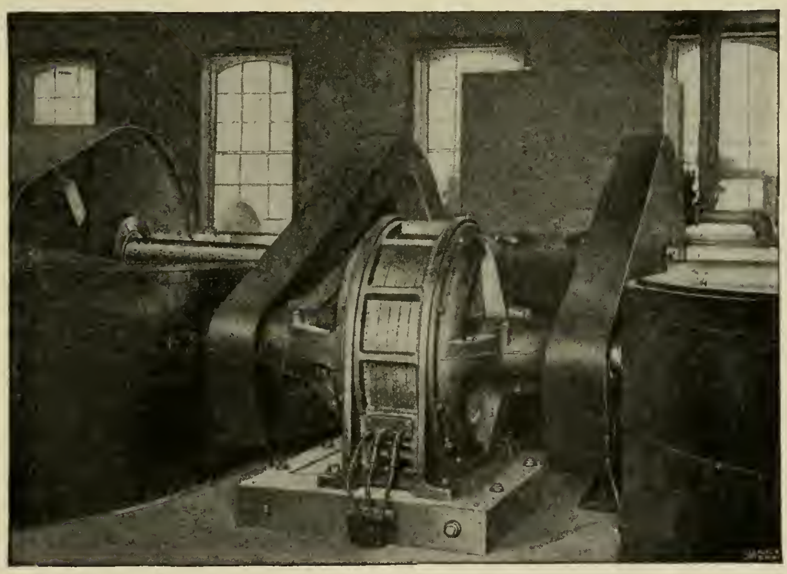


Fig. 28. Induction Motor Driving Two Beaters Through Silent Chain
Courtesy of General Electric Company

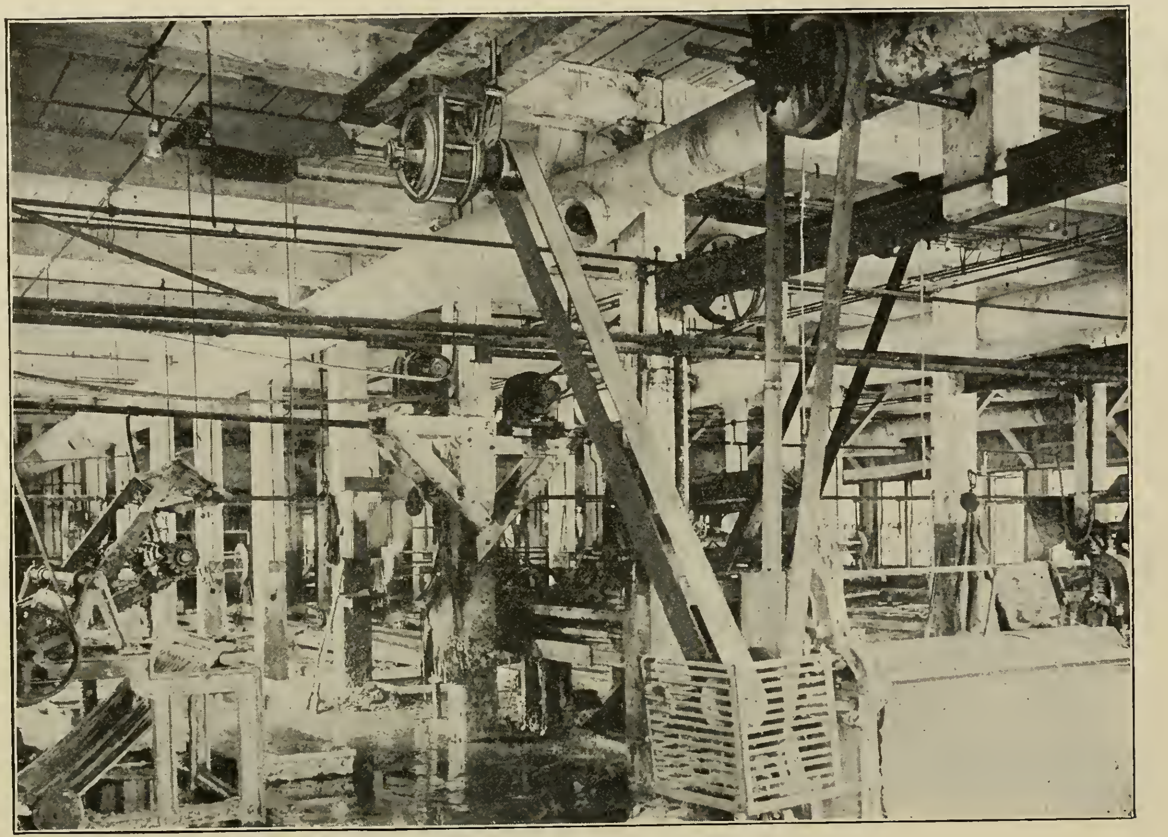


Fig. 29. Small Motors Driving Unhairing and Fleshing Machine
Courtesy of General Electric Company

constant high speeds necessary in the operation of shoe machinery in order to obtain maximum production. As there is no necessity for a variation of speed, the induction motor is peculiarly adapted to this task.

Group drive is recommended for this work, as the power required on these machines is intermittent. The group drive combines the most economical method of operation and the lowest first cost for wiring and electrical equipment.

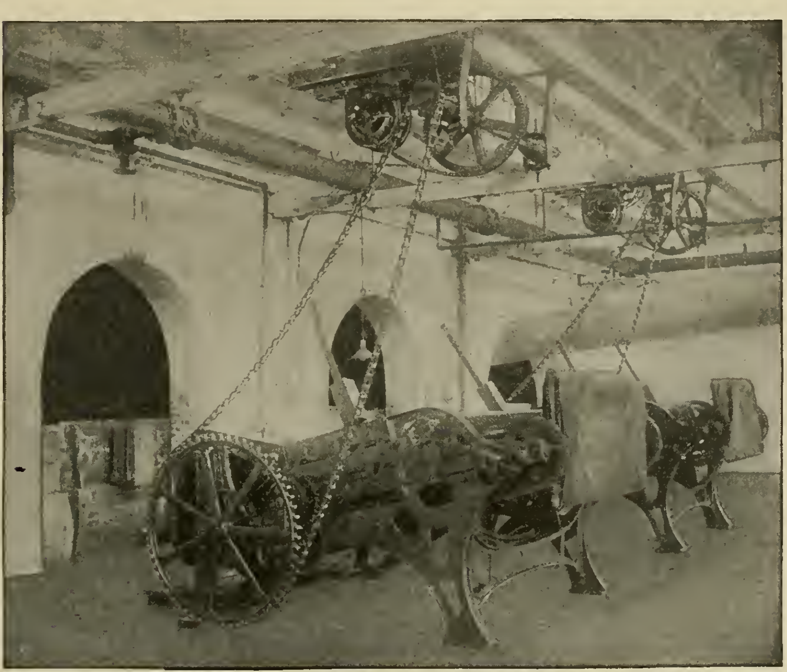


Fig. 30. Silent Chain Drive for Setting-Out Machines
Courtesy of General Electric Company

Motor Applications. Fig. 29 shows a scene in the unhairing and fleshing room of the factory of Endicott, Johnson and Company. The motors for work of this class are suspended from the ceiling or posts, thus being out of the way of the liquids used. The installation shown consists of a 7½- and a 10-horsepower motor, belted to the unhairing and fleshing machines. Fig. 30 shows a setting-out machine driven by a 5-horsepower motor connected through a silent chain drive to a jack shaft and from the jack shaft to a sprocket wheel on the machine by means of a loose sprocket chain.

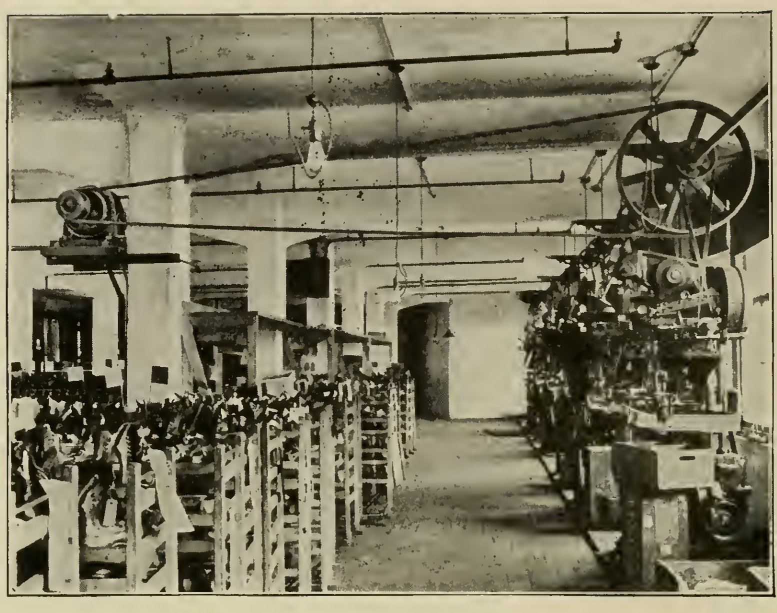


Fig. 31. Small Motor Driving Countershaft for Heeling Machines
Courtesy of General Electric Company

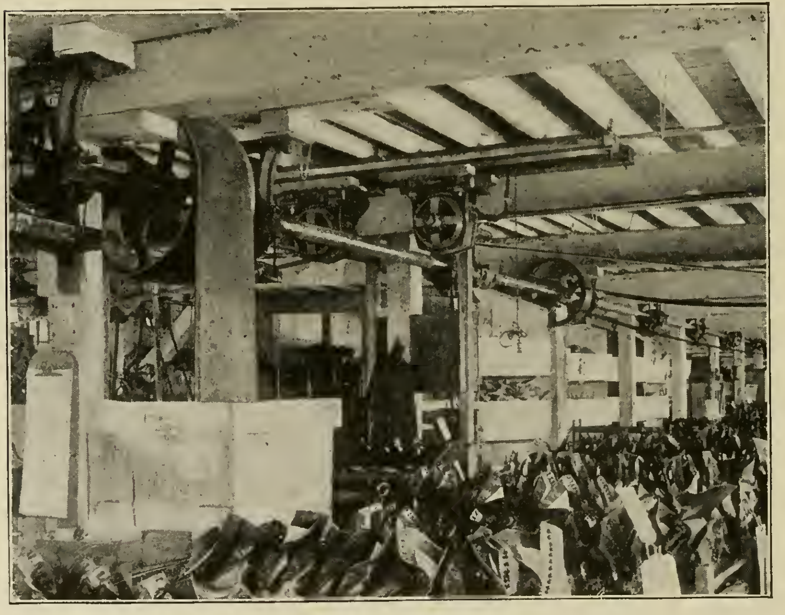


Fig. 32. Motor Installation Contrasted with Old Type Line Shafting
Courtesy of General Electric Company

In Fig. 31 the group drive is very clearly illustrated, the motor being fastened to a platform resting on iron brackets bolted to a column. This installation is in the plant of John H. Cross and Company, Cambridge, Massachusetts, and shows a 7½-horsepower 550-volt General Electric motor belted to a jack shaft and driving heeling machines. In Fig. 32 the reader can get some idea of the advantage of the electric drive over the mechanical drive. Here 7½-horsepower General Electric motors have replaced a 3½-inch main shaft in the Springvale Shoe Works. Note the long line of shafting, hangers, drive pulley, and large belt, which with their attendant friction have been eliminated by the small motor drive. Besides reducing the friction, the elimination of belts and shafting gives added floor space and better light.

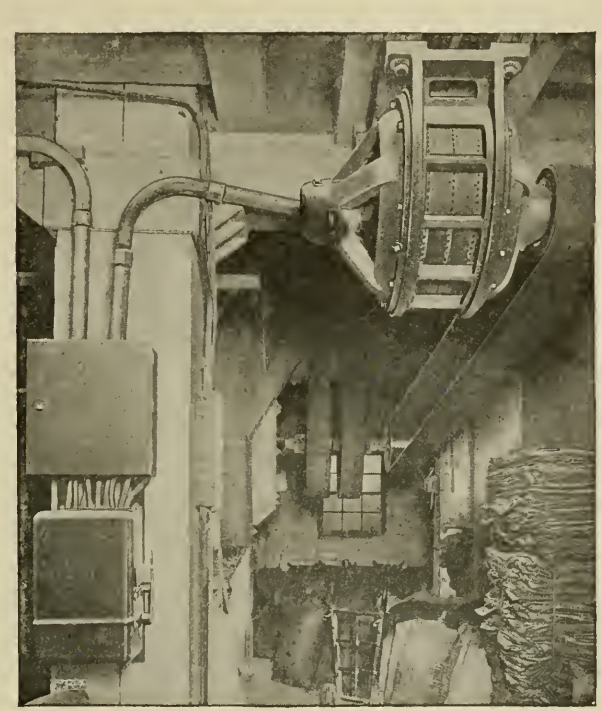


Fig. 33. Ceiling Installation of Induction Motor
Courtesy of General Electric Company

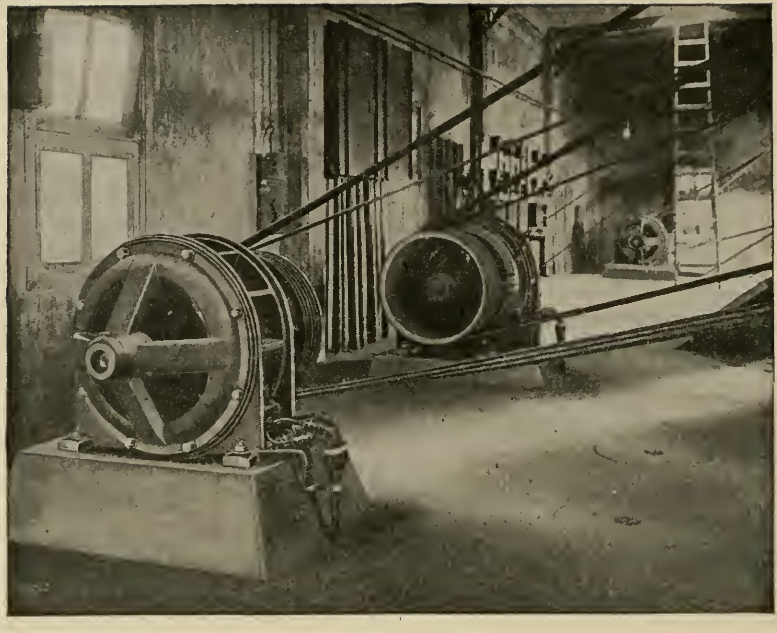


Fig. 34. Induction Motors Driving Elevator Legs
Courtesy of General Electric Company

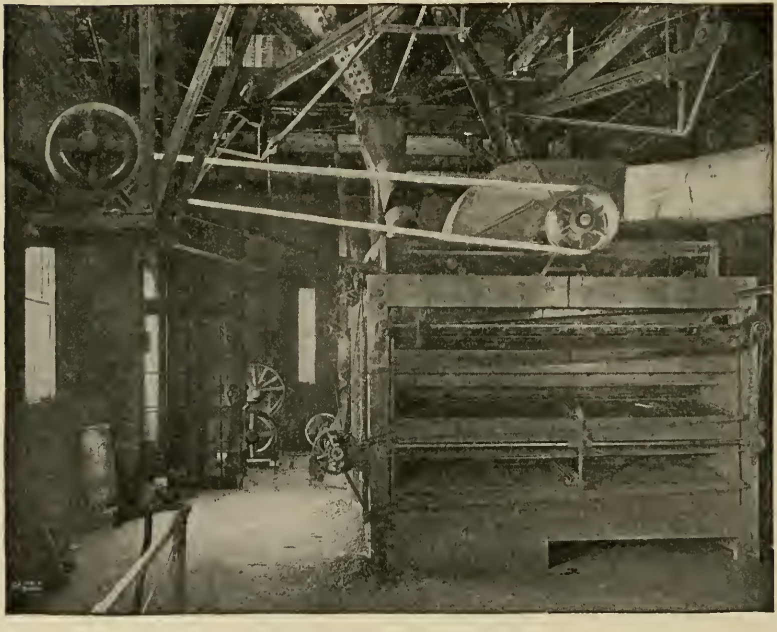


Fig. 35. Induction Motor Belted to Cleaner
Courtesy of General Electric Company

FLOUR MILLS AND ELEVATORS

In flour mills and elevators, as in all other industries where it is desired to change from the mechanical to the electrical drive, an analysis of all the factors entering into the cost of power and methods used to apply it must be carefully considered. Much of the machinery must be run at constant speed, and as the induction motor is essentially a constant-speed motor and is durable and reliable, it has been extensively used by many of the largest mills. The motors can be placed near the machines operated and connected to them by short belts or by short rope drives, thus eliminating the greater part of the friction.

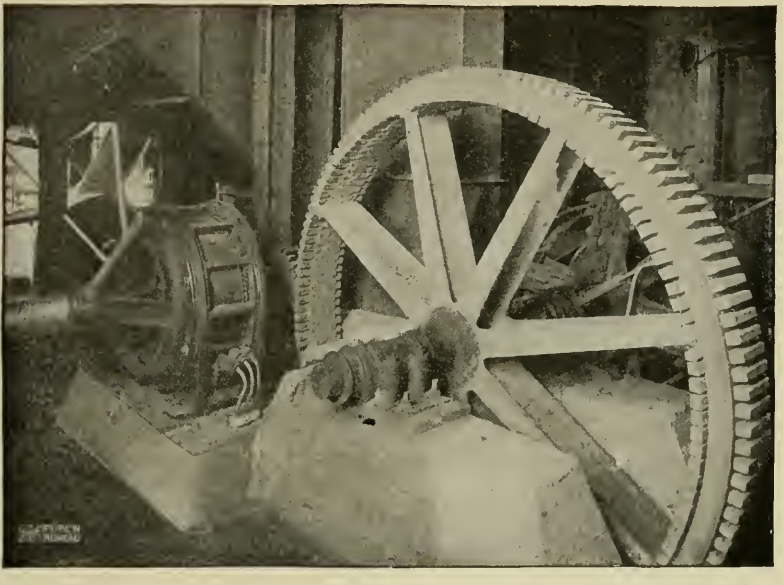


Fig. 36. Induction Motor Driving Belt Conveyor in Washburn-Crosby Mill
Courtesy of General Electric Company

For the type of mill under consideration, a combination of the group and individual drive seems to be the best up-to-date practice; for example, elevator legs, car pullers, and exhaust fans should each be operated by a separate motor, while the separators, conveyors, and dust collectors should be grouped under one drive.

Applications. In Fig. 33 is shown a 50-horsepower General Electric induction motor installed in a chop mill. This motor is

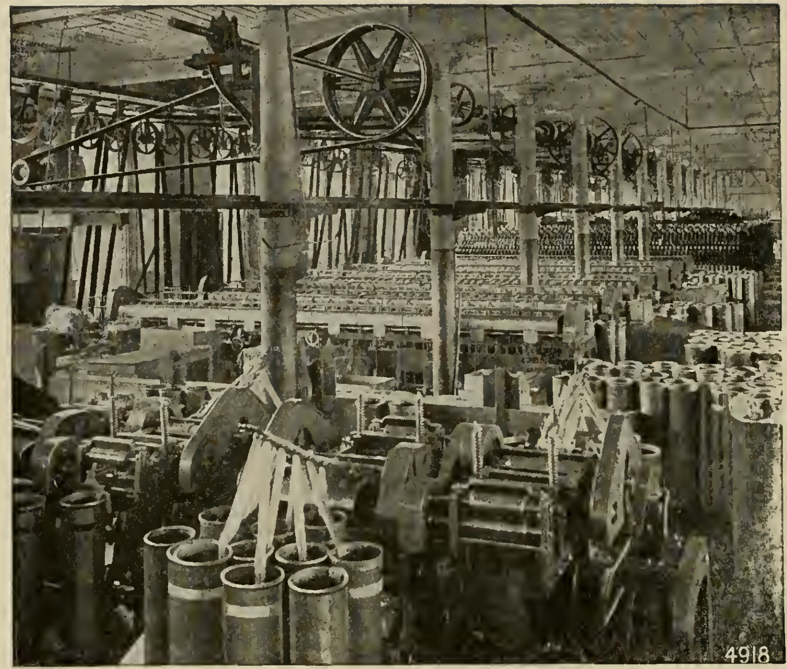


Fig. 37. Interior of Textile Mill Before Silent Chain Drive Was Installed
Courtesy of Link-Belt Company

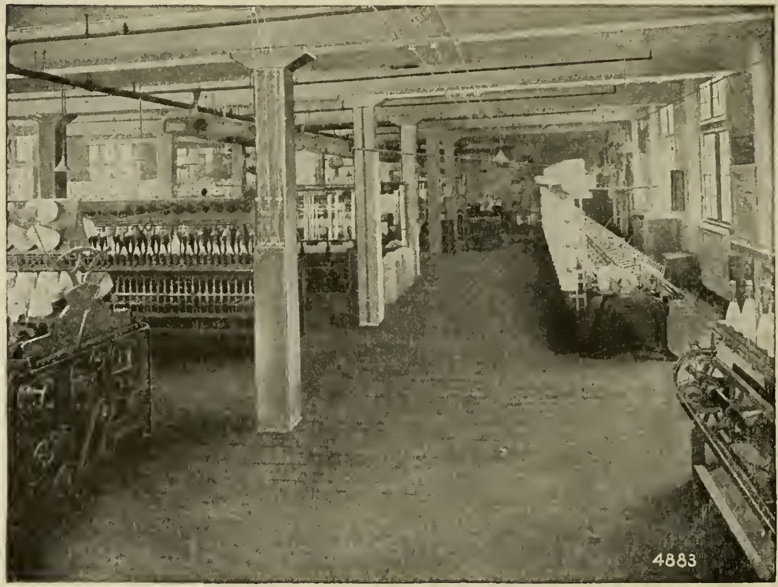


Fig. 38. Interior of Textile Mill Where Silent Chain Is Used Exclusively
Courtesy of Link-Belt Company

belted to the main drive, and being suspended from the ceiling, is out of the way, leaving clear floor space under it. This is the most economical power for the small mill situated where all-day current can be obtained.

Fig. 34 shows two induction motors driving elevator legs in a Washburn-Crosby mill; in Fig. 35 is shown an induction motor belt-connected to a cleaner; while Fig. 36 shows a 30-horsepower induction motor driving a belt conveyor in a Washburn-Crosby mill.

TEXTILE MILLS

In the textile industry it is necessary to have all machines operated at constant speed, as a small variation in speed, due to slipping of belts, will very materially affect the quality of the product. With engine and mechanical drive it is practically impossible to produce constant speed at the machines, and it has, therefore, become the practice to install a motor for each machine. In this way the stopping or starting of any one machine or series of machines has no effect on the speed of the machines in operation. As a further advantage of motor drive, Figs. 37 and 38 show what can be accomplished in producing better light by eliminating shafts, belts, and pulleys.

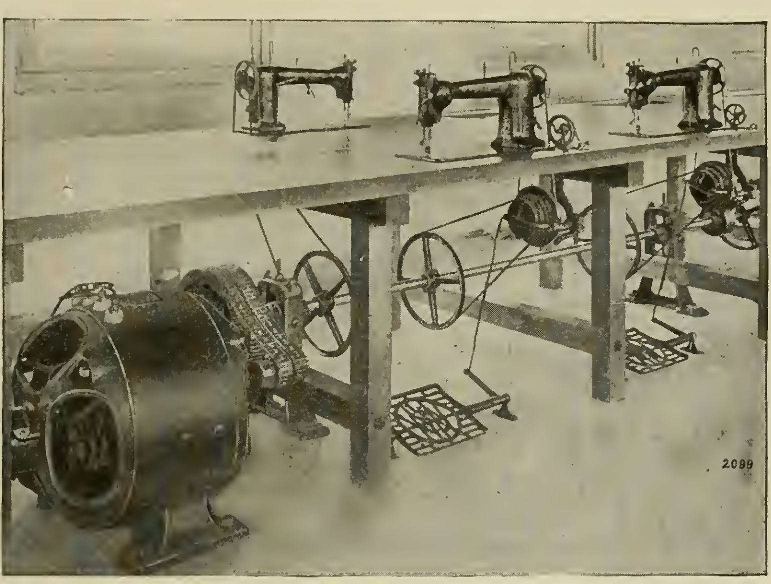


Fig. 39. Silent Chain Drive for Sewing Machines
Courtesy of Link-Belt Company

Silent Chain Transmission. One of the most important things to be considered in a modern textile mill is the method of transmitting power to various machines. Practice has shown that the link-belt silent chain is particularly suited to driving textile machinery, as it gives a steady and positive drive and prevents the slipping that necessarily attends a short belt drive. In Table II of the Appendix

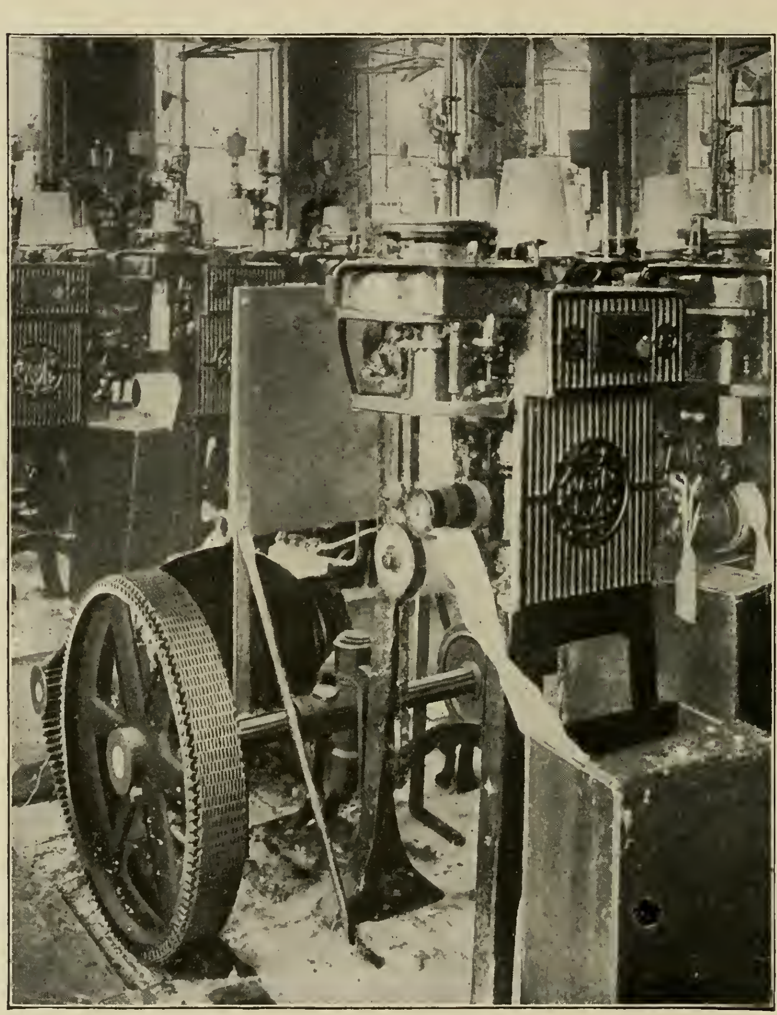


Fig. 40. Silent Chain Operating Knitting Machines
Courtesy of Link-Belt Company

is given some data furnished by the Link-Belt Company for determining the sizes of chain to deliver any horsepower at certain speeds.

Applications. Fig. 39 shows a 5-horsepower motor operating a sewing machine line shaft. The motor is bolted to rails on the floor under the bench and is connected to the shaft through a silent chain. In Fig. 40 a 5-horsepower motor is connected to knitting machines. Note the compactness of the installation; the chain drive admits of the motor being set close up to the shaft, giving greater clear floor space than is possible with the leather belt. An exposed drive like the one in this illustration should always be surrounded by a metal case to protect employes from personal injury, a hazard to be kept in mind in every installation where gears or belts are exposed. Fig. 41 shows a 5-horsepower motor on a winding machine. The ease with which this application can be made is apparent. Note the metal case protective device covering the chain.

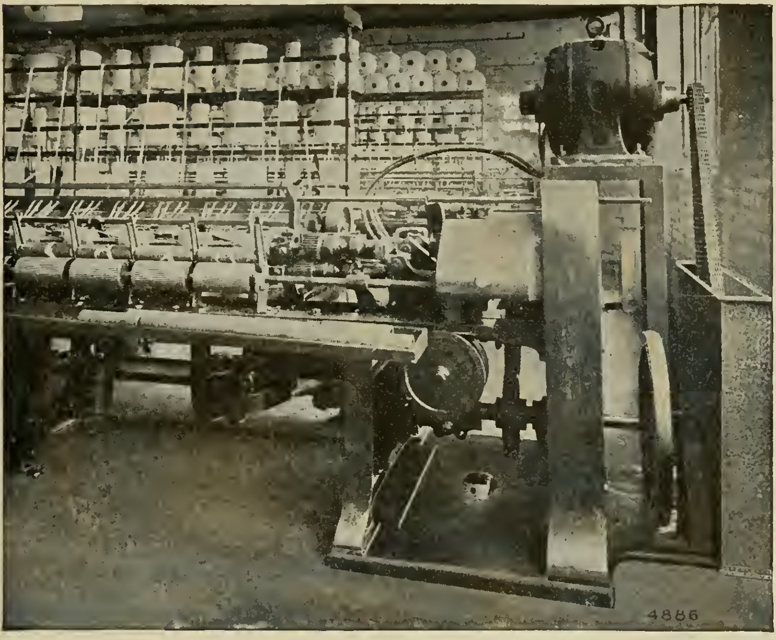


Fig. 41. Motor and Silent Chain Operating Winding Machine
Courtesy of Link-Belt Company

CEMENT PLANTS

Type of Drive. The electric drive is admirably adapted to power work in a cement manufacturing plant. In most cases the individual drive is used, the motor being belted to kilns, compressors, conveyors, and crushers. In the ball mills, the machines are driven from a long shaft which in turn is coupled at each end directly to a motor. The mills are disconnected from the main shaft by means of friction clutches, being coupled in after the motor has obtained full speed. The induction motor is recommended for this work—single-phase for small powers, and polyphase for large powers where the distance over which the power is transmitted is great.

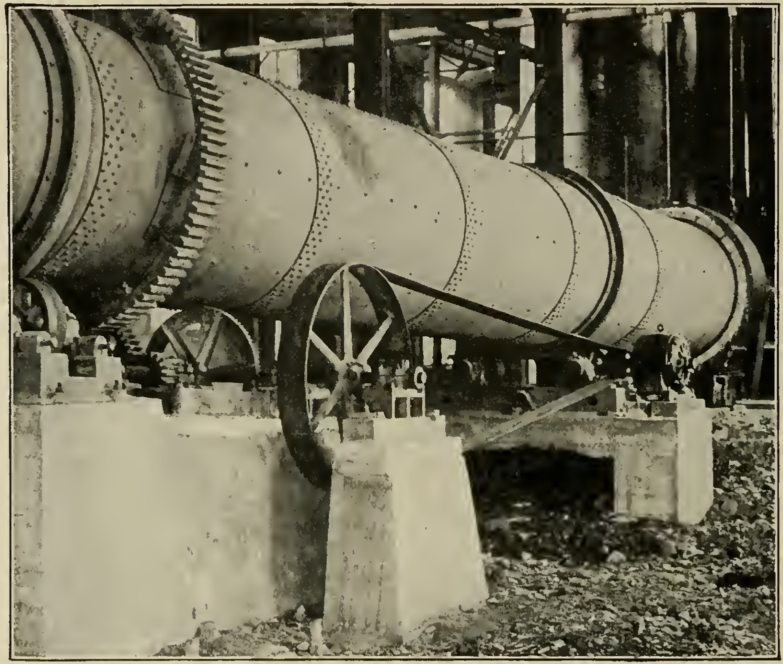


Fig. 42. Wagner Motor Operating Dryer Kiln
Courtesy of Wagner Electric Manufacturing Company

Applications. In Fig. 42 is shown a 15-horsepower Wagner motor, running at 750 r. p. m. and operating a dryer kiln. Fig. 43 is a front view of two rotary kilns and two 35-horsepower Wagner motors operating air compressors for oil feed. This installation could be improved by placing the compressors and motors in a small building

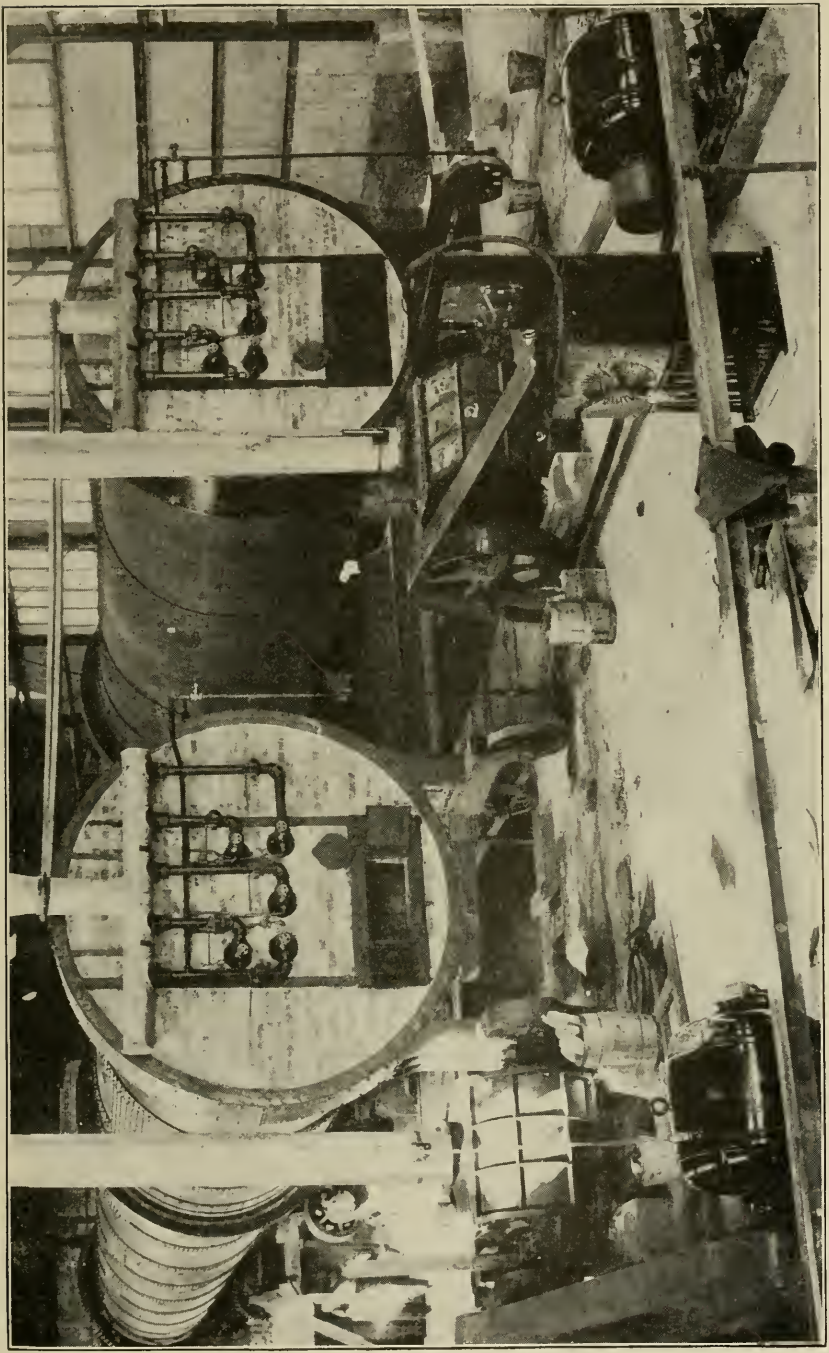


Fig. 43. Front View of Two Rotary Kilns and Motor Installation for Air Compressors
Courtesy of Wagner Electric & Manufacturing Company

adjacent to this kiln room, thus giving the kiln operators more room and removing the motors and starters from the heat and dust directly in front of the kilns.

Fig. 44 shows a 75-horsepower Wagner motor operating an Austin crusher, and a 50-horsepower motor operating a Williams crusher.

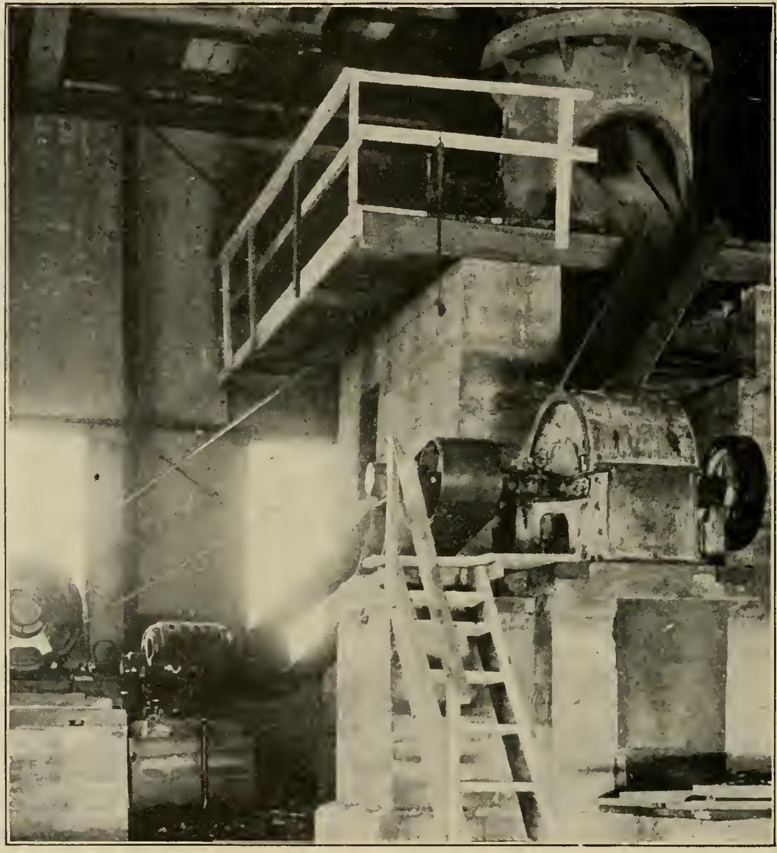


Fig. 44. Wagner Motors Operating Austin and Williams Crushers
Courtesy of Wagner Electric & Manufacturing Company

MINING INDUSTRY

The extensive use of electricity in mining is due chiefly to the high efficiency of modern electrical machinery, and to the desirability of eliminating long lines of steam and air piping necessary to convey power from plant to mine. Large horsepowers may easily

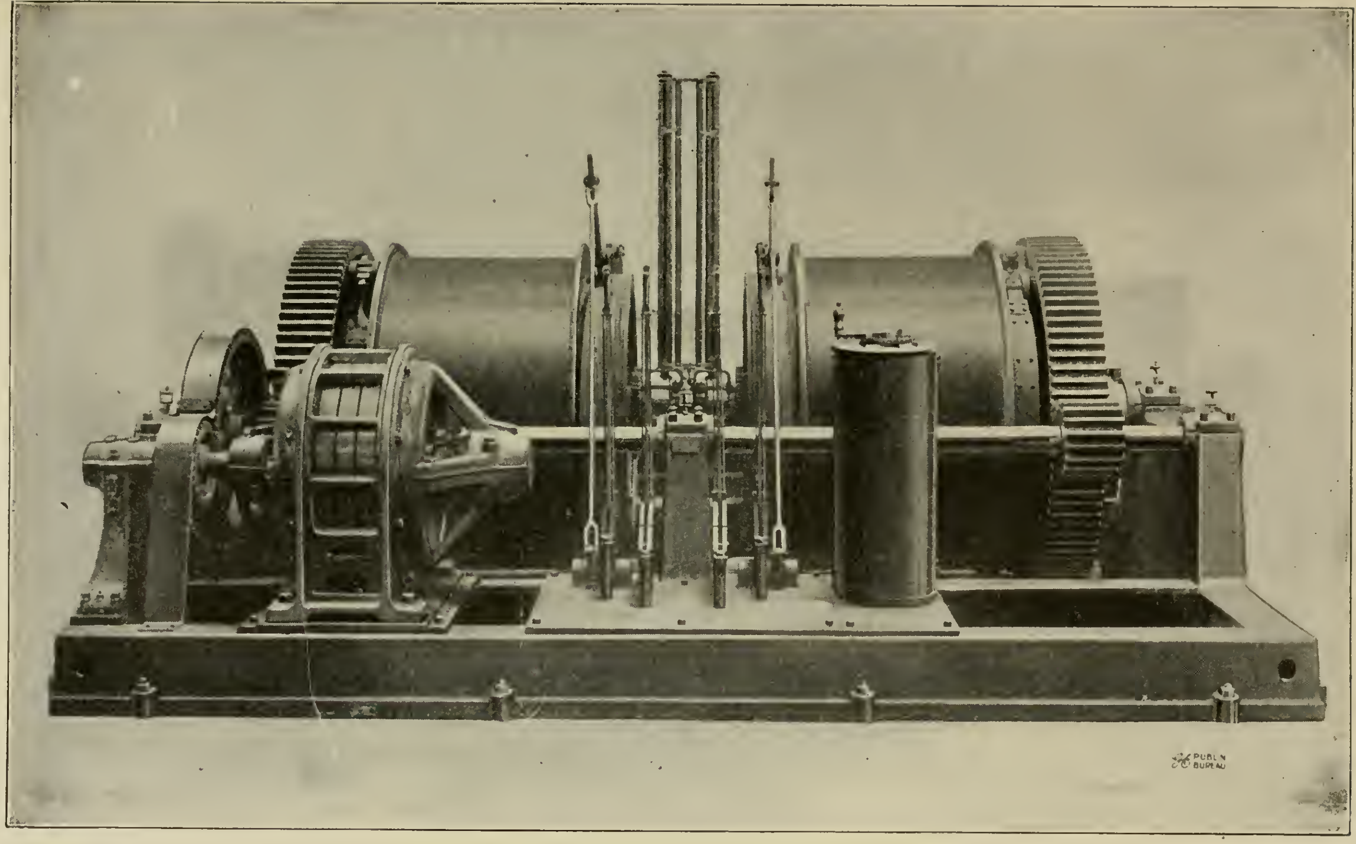


Fig. 45. Double Drum Electric Hoist Run by Induction Motor
Courtesy of General Electric Company

be transmitted by electricity at a very small loss over long distances, thus making it possible to develop a hydro-electric plant of sufficient capacity for several properties, with a corresponding saving in the cost of installation and maintenance. The flexibility of the motor drive renders possible the use of portable machinery and allows the relocation of existing machines without interfering with the operation of the remainder of the equipment.

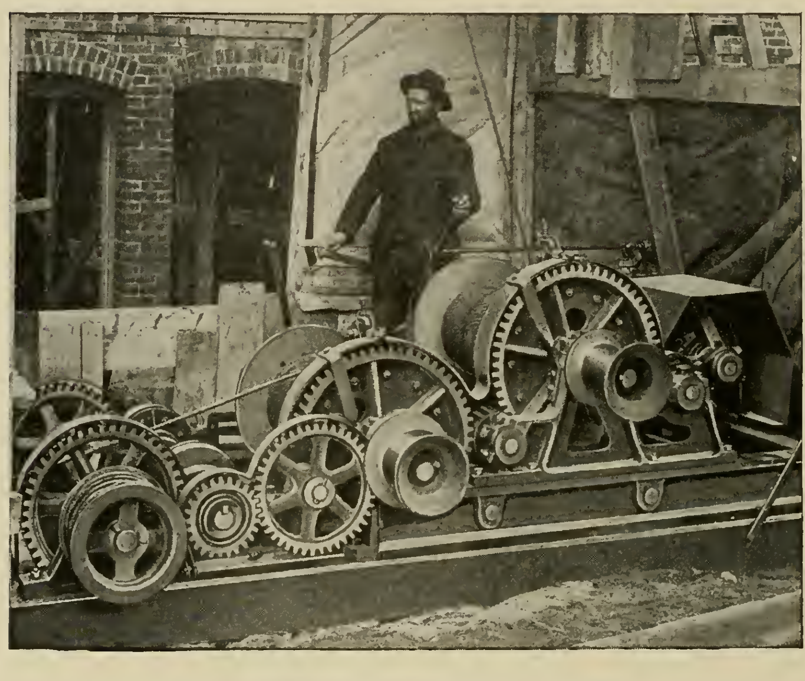


Fig. 46. Electric Hoist Used in Building Construction
Courtesy of General Electric Company

Applications. The electric motor is used for drills, hoisting and pumping machinery, ventilating fans, conveyors, breakers, electric locomotives, and coal-cutting machines. In Fig. 45 is shown the double drum electric hoist driven through gears by a General Electric variable-speed induction motor. The electric hoist and motor are mounted on a single cast-iron base, forming a very compact unit. Fig. 46 shows an electric hoist used in building construction. An electric drill is clearly illustrated in Fig. 47 connected by belt to the rotary hammer shown in Fig. 48. The mechanism of the drill consists of two parts, a revolving helve containing the hammers, and the chuck mechanism for holding and rotating the drill steel. As the helve revolves the hammer is thrown outward by centrifugal

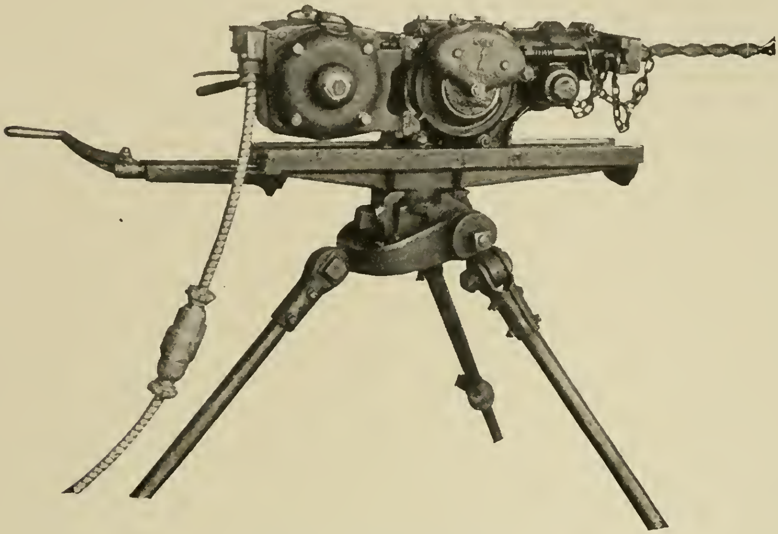


Fig. 47. Electric Rock Drill
Courtesy of Fort Wayne Electric Works

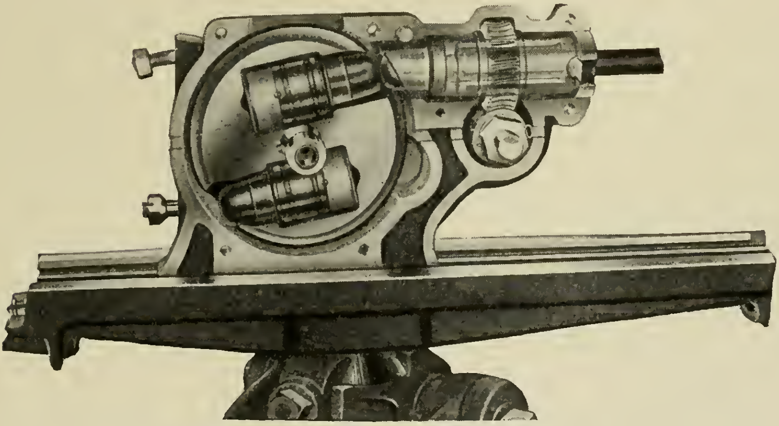


Fig. 48. Partially Dismounted Rock Drill Showing Electrical Hammer Mechanism
Courtesy of Fort Wayne Electric Works

force and at each revolution strikes a blow upon the projecting head of the drill steel cap, which in turn delivers the energy of the blow to the drill steel.

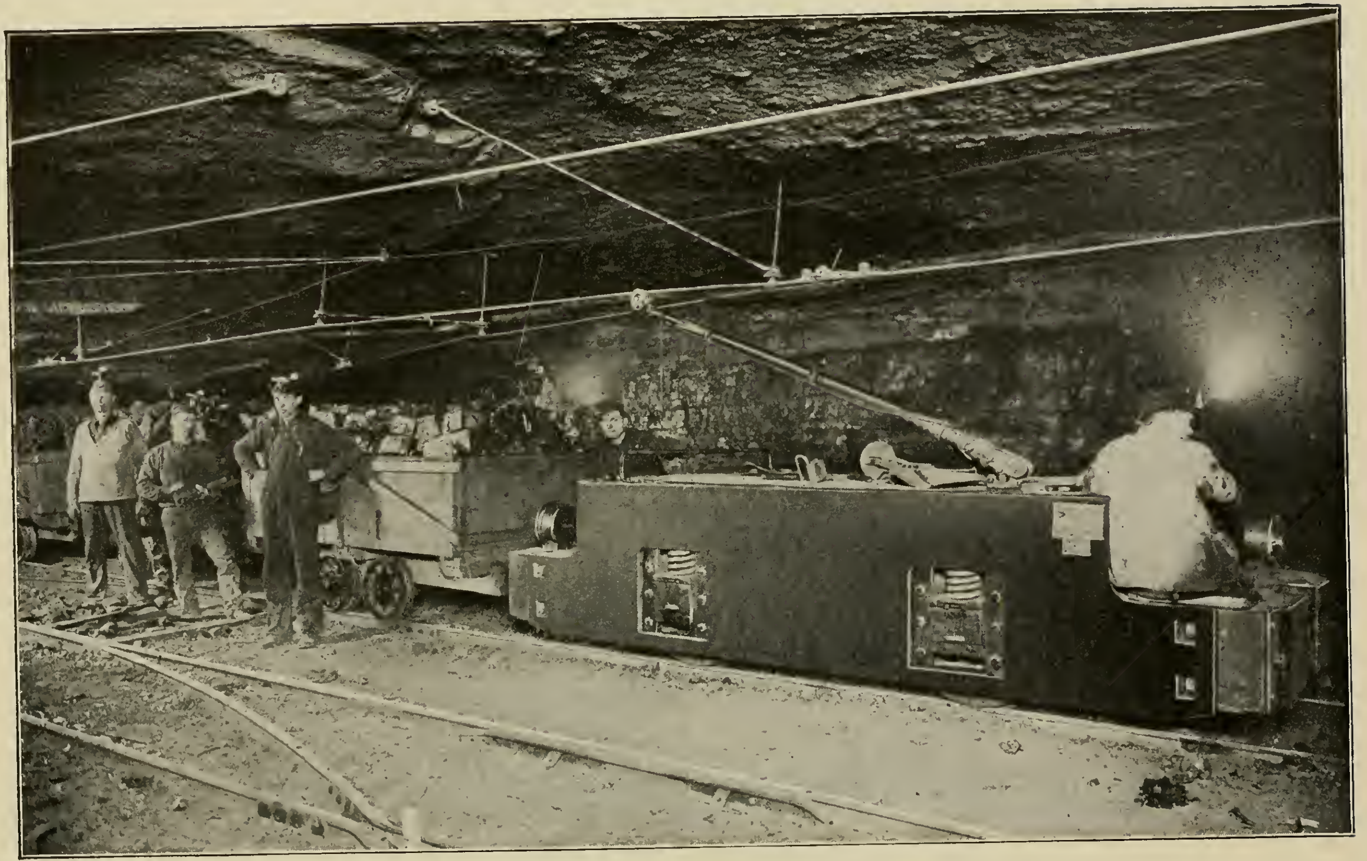


Fig. 49. Mine Locomotive Operating for the Consolidated Coal Company of St. Louis
Courtesy of General Electric Company

In Figs. 49 and 50 may be seen an electric mine locomotive of General Electric manufacture, the former portraying the locomotive, trolley, and tracks in the mine of the Consolidated Coal Company of St. Louis, Missouri, while the latter shows the electric motor geared to the locomotive axle. Either direct- or alternating-current motors may be used for mine haulage.

One of the most important applications of the electric motor in the mine is that of the Sullivan coal cutter, shown in Fig. 51. This figure illustrates the machine in working position crossing the face of the vein in an Illinois mine. The machine consists of three principal parts—a cutter bar with a continuous chain, carrying teeth or bits; a motor which drives the cutter chain through gearing or sprockets and feeds the machine along the face; and a frame or pan on which the working parts are mounted.

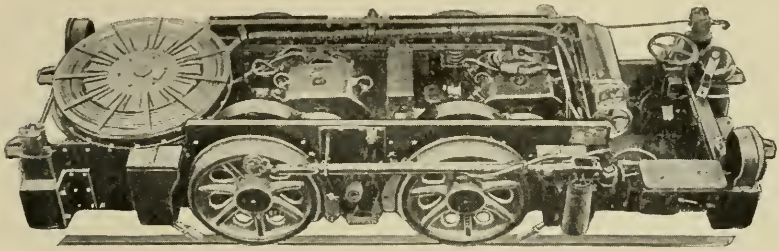


Fig. 50. Electric Truck for Electric Locomotive Shown in Fig. 49
Courtesy of General Electric Company

The direct-connected motor and centrifugal pump have come into extensive use for mine work as being the most efficient, compact, and flexible installation possible. Fig. 52 portrays a 150-horsepower General Electric 220-volt motor direct-connected to a four-stage 10-inch centrifugal pump operating against a 330-foot head, capacity 1000 gallons per minute. Fig. 53 shows a 300- to 150-horsepower two-speed induction motor driving a ventilating fan by means of a flexible coupling.

In Fig. 54 is given an illustration of a Sullivan air compressor mounted on a base with a direct-current motor. The motor drives the compressor through a silent chain. Fig. 55 shows a motor, air compressor, and air tank, all mounted on a mine truck. This equipment is especially valuable for operating air drills in metal mines.

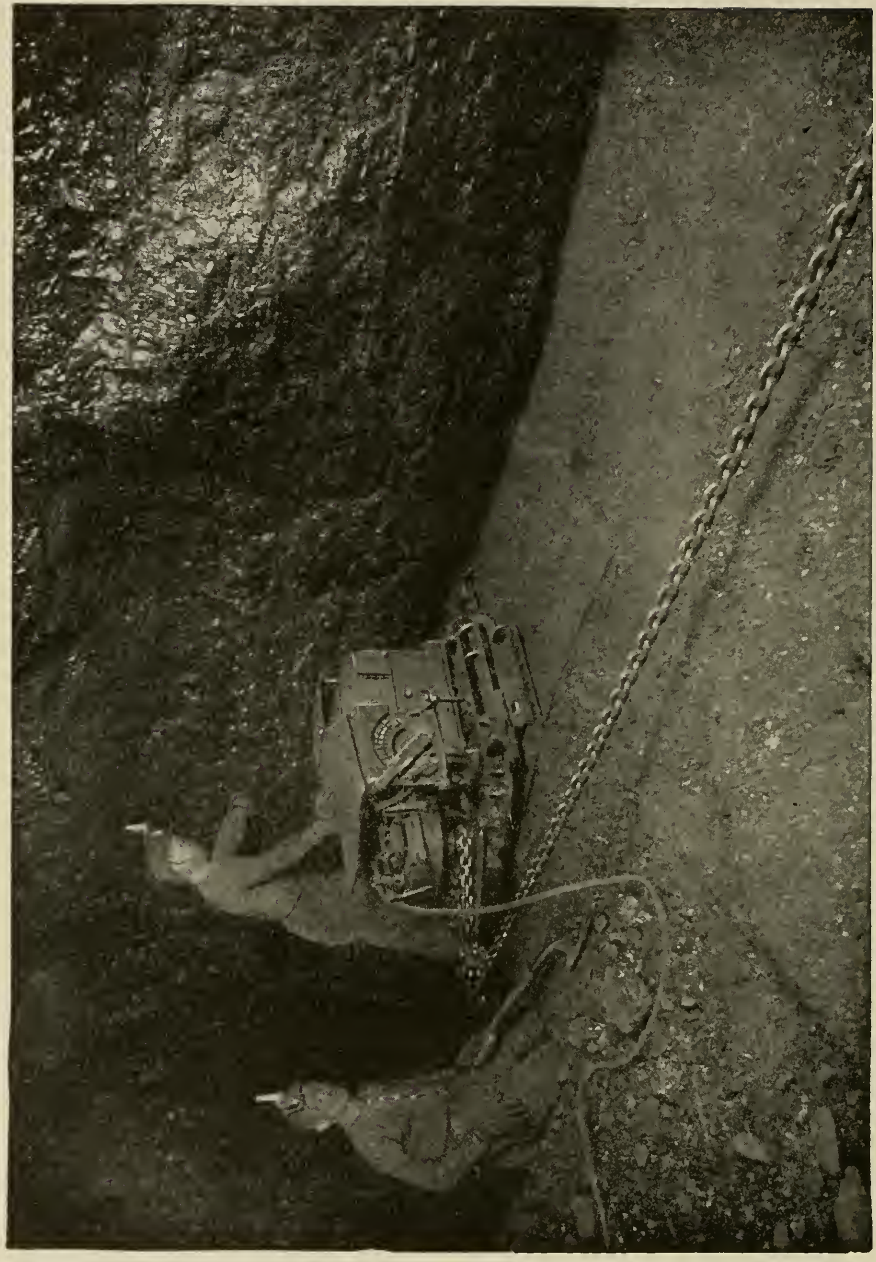


Fig. 51. Sullivan Coal Cutter Crossing the Face in an Illinois Mine
Courtesy of Sullivan Machinery Company

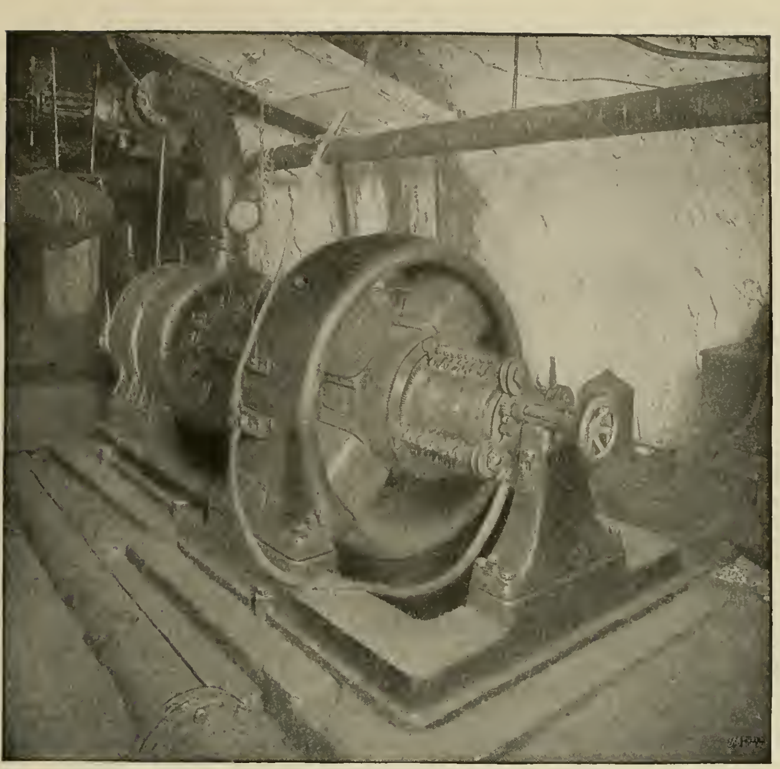


Fig. 52. General Electric Motor Operating a Four-Stage Centrifugal Pump
Courtesy of General Electric Company

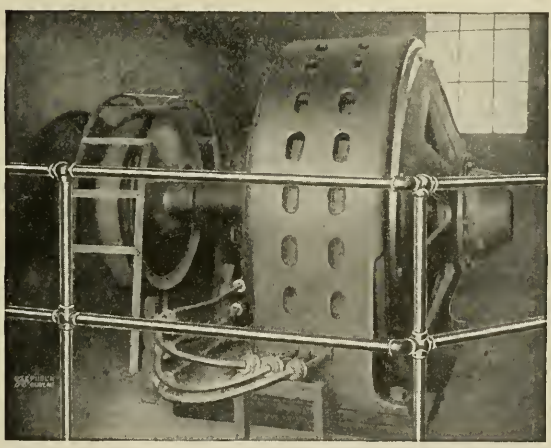


Fig. 53. Induction Motor Operating Ventilating Fan Through Flexible Coupling
Courtesy of General Electric Company

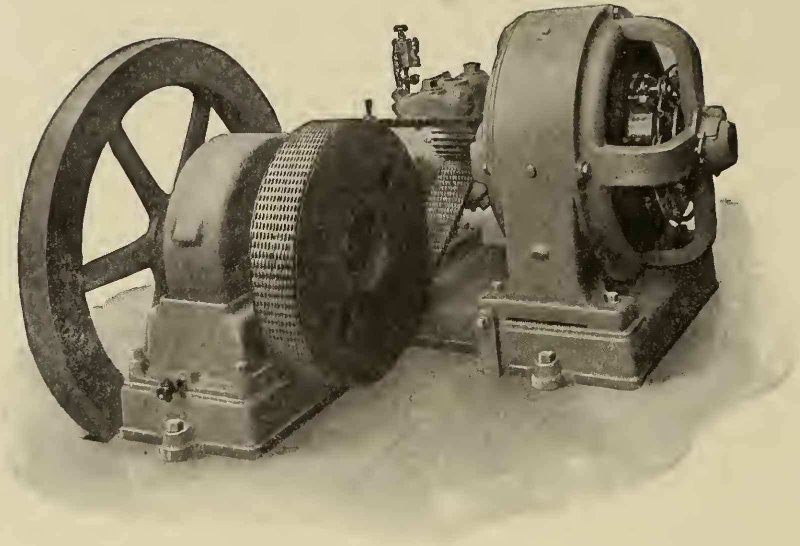


Fig. 54. Motor Operating Sullivan Air Compressor Through Silent Chain
Courtesy of Sullivan Machinery Company

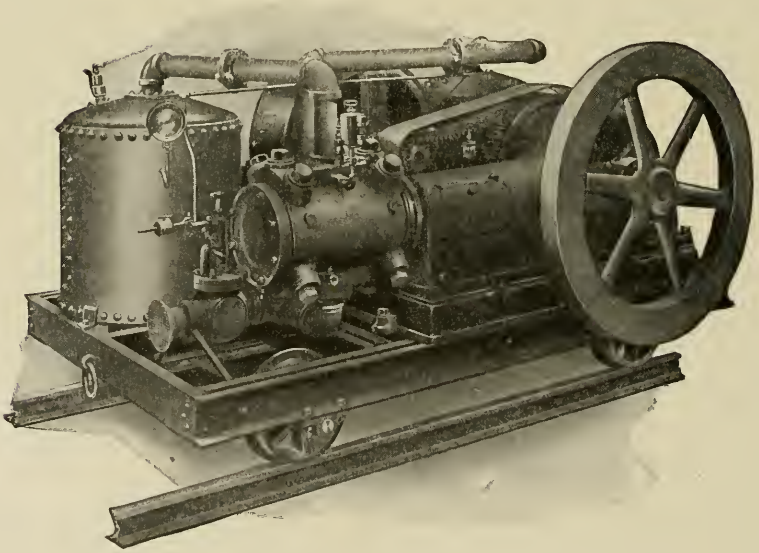


Fig. 55. Motor, Air Compressor, and Tank Mounted on a Mine Truck
Courtesy of Sullivan Machinery Company

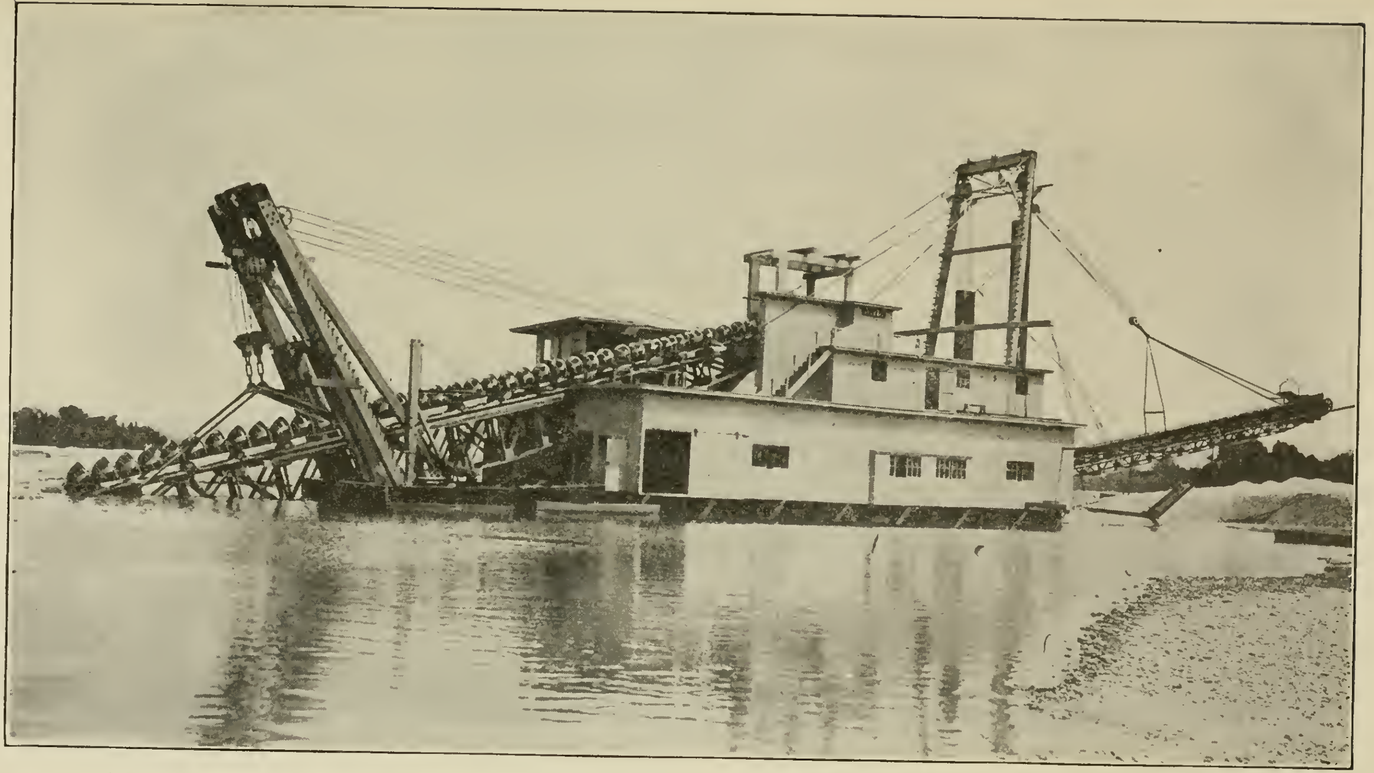


Fig. 56. Gold Dredge for the Yuba Construction Company Equipped with General Electric Motors and Other Electrical Apparatus
Courtesy of General Electric Company

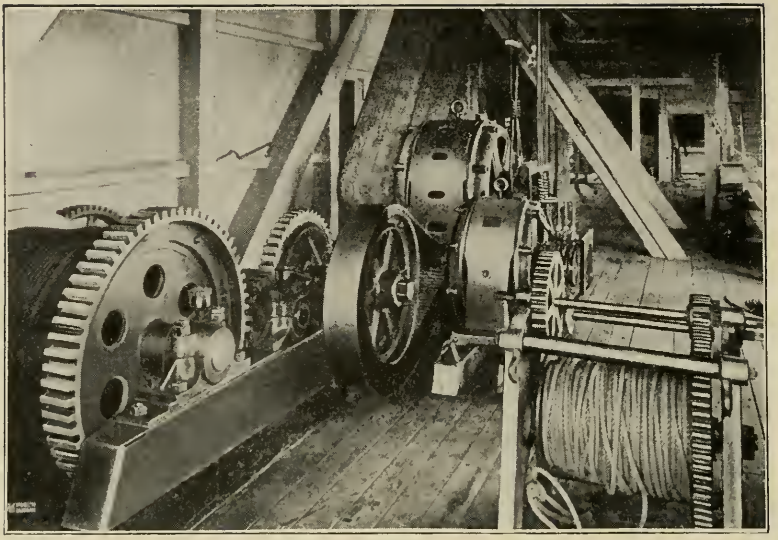


Fig. 57. Bucket Line and Winch Motors for Dredge Shown in Fig. 56
Courtesy of General Electric Company

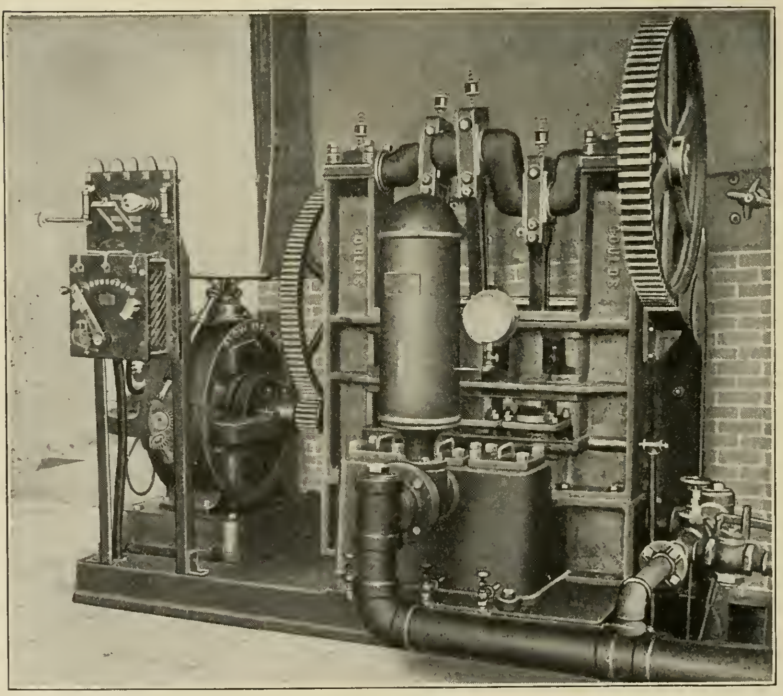


Fig. 58. Stow Multispeed Motor Driving Gould Pump
Courtesy of Stow Manufacturing Company

GENERAL APPLICATIONS

ENGINEERING

The electric drive is adapted to the driving not only of industrial machinery but of machinery used in general contracting as well, replacing the steam shovel in excavating and in dredging, and furnishing the power in the municipal pumping plant, the refrigerating plant, and the quarry. In Fig. 56 is given an illustration of a dredge used in placer gold mining. This is gold dredge No. 11, of the Yuba Construction Company, of Marysville, California. The electrical equipment consists of three 125-kilowatt 60-cycle 4000- to 460-volt three-phase transformers; one 7½-kilowatt 4000- to 115- and 230-volt transformer switchboard; seven 440-volt induction motors ranging from 10 to 250 horsepower. Fig. 57 shows the application of two of these motors, one belted to the bucket line and the other connected to the winch or hoisting drum by chain drive.

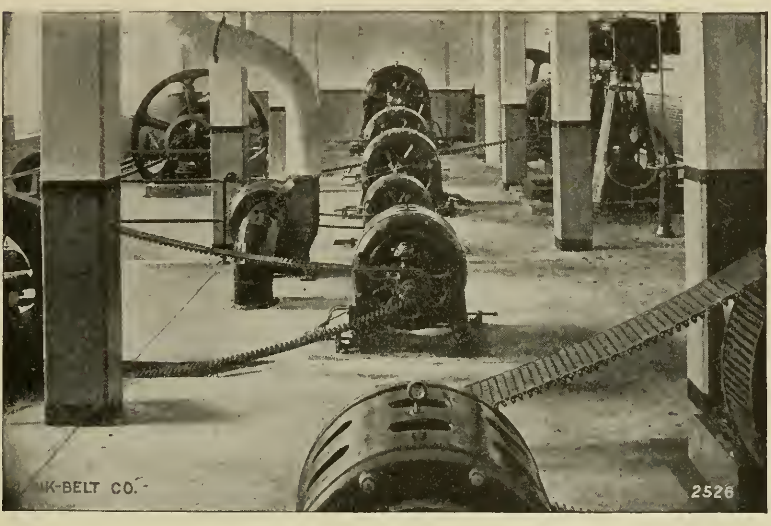


Fig. 59. Motors Driving Refrigerating Machines Through Silent Chain
Courtesy of Link-Belt Company

In Fig. 58 is shown a very compact pump installation. Here the adjustable-speed Stow motor and triplex pump are geared together and mounted on the same base. Fig. 59 shows a group of motors operating refrigerating machines through a link-belt silent chain drive. Fig. 60 illustrates the ease and flexibility of application of the motor to quarry machinery.

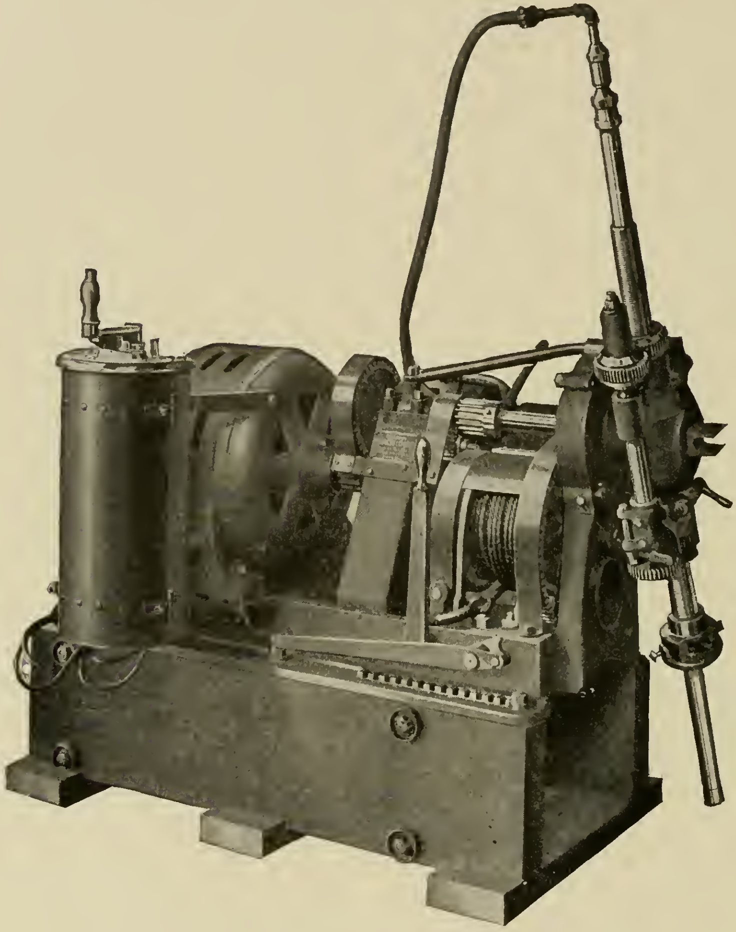


Fig. 60. Sullivan Electric Diamond Drill Driven by Motor
Courtesy of Sullivan Machinery Company

DOMESTIC

The applications of the electric drive to labor-saving devices for the home are too numerous to admit of a discussion of all of them here. Fig. 61 shows a Thor washing machine driven by a small motor by means of belt drive. Fig. 62 illustrates a small motor operating an ironer; the motor is mounted on a platform bolted to the machine and is belted to the drive pulley operating the rolls.

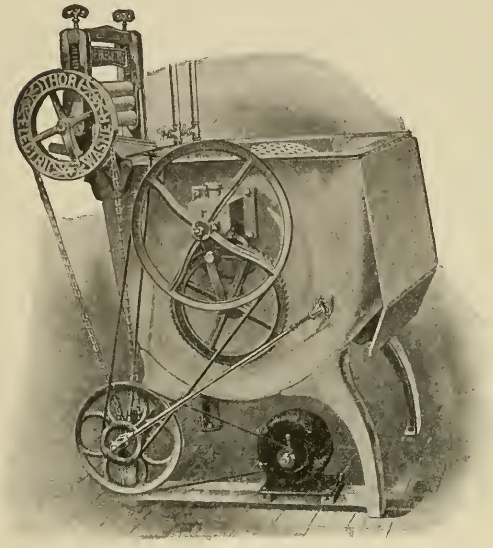


Fig. 61. Thor Washing Machine Driven by a Small Motor
Courtesy of Hurley Machine Company

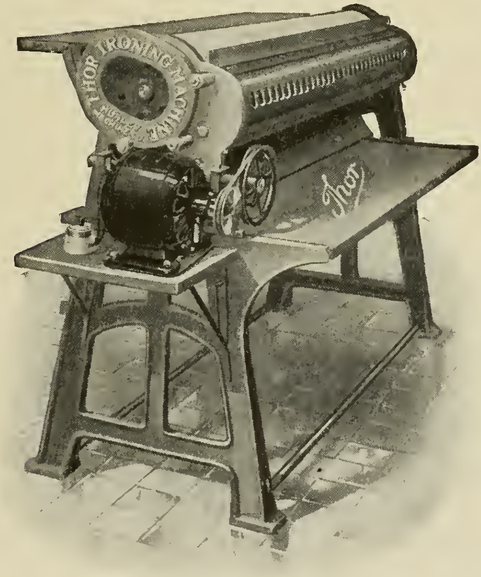


Fig. 62. Thor Ironing Machine, Motor Driven
Courtesy of Hurley Machine Company

APPENDIX

TABLE I

Ratings and Classes of Motors

In the following tables, published by the Westinghouse Electric and Manufacturing Company, the horsepower recommended is based on average practice; it may be decreased for very light work and must often be increased for heavy work. The class of motor is indicated by the symbols A, B, C explained below. The meaning of these symbols is sometimes modified by notes under the tables.

(A) Adjustable-speed shunt-wound direct-current motors wherever a number of speeds are essential.

(B) Constant-speed shunt-wound direct-current motors where the speeds are obtainable by a gear box or cone pulley arrangement or where only one speed is required.

(C) Squirrel-cage induction motor where direct current is not available. A gear box or cone pulley arrangement must be used to obtain different speeds.

BOLT AND NUT MACHINERY

Bolt Cutters

Motor—A, B, or C

	Size—Inches	H.P.
Single	1, 1¼, 1½	1 to 2
	1¾, 2	2 to 3
	2¼, 3½	3 to 5
	4, 6	5 to 7½
Double	1, 1½	2 to 3
	2, 2½	3 to 5
Triple	1, 1½, 2	3 to 7½

Bolt Pointers

Motor—B or C

1½, 2½	1 to 2

Nut Tappers

Motor—A, B, or C

Four-spindle	1, 2	3
Six-spindle	2	3
Ten-spindle	2	5

Nut Facing

Motor—B or C

1, 2	2 to 3

BOLT HEADING, UPSETTING AND FORGING

Motor—A*, B†, or C‡

Size—Inches	H.P.
¾ to 1½	5 to 7½
1½ to 2	10 to 15
2½ to 3	20 to 25
4 to 6	30 to 40

*Speed variation is sometimes desired when different sizes of bolts are headed on the same machine.

†Compound-wound direct-current motor.

‡Wound secondary or squirrel-cage motor with approximately 10 per cent slip.

BORING AND TURNING MILLS

Motor—A, B, or C

	Horsepower	
Size	Average	Heavy
37 to 42 inches	5 to 7½	7½ to 10
50 inches	7½	7½ to 10
60 to 84 inches	7½ to 10	10 to 15
7 to 9 feet	10 to 15	30 to 40
10 to 12 feet	10 to 15	
14 to 16 feet	15 to 20	
16 to 25 feet	20 to 25	

BULLDOZERS OR FORMING OR BENDING MACHINES

Motor—B* or C†

Width—Inches	Head Movement, Inches	H.P.
29	14	5
34	16	7½
39	16	10
45	18	15
63	20	20

*Compound-wound motor.

†Wound secondary or squirrel-cage motor with approximately 10 per cent slip.

BUFFING LATHES

Motor—B or C

Wheels		
No.	Dia.—Inches	H.P.
2	6	¼ to ½
2	10	1 to 2
2	12	2 to 3
2	14	3 to 5

For brass tubing and other special work use about double the above horsepower.

DRILLING AND BORING MACHINES

Motor—A, B, or C

	H.P.
Sensitive drills up to ½ inch	¼ to ¾
Upright drills, 12 to 20 inches	1
Upright drills, 24 to 28 inches	2
Upright drills, 30 to 32 inches	3
Upright drills, 36 to 40 inches	5
Upright drills, 50 to 60 inches	5 to 7½

DRILLING AND BORING MACHINES—Continued.

	Horsepower Heavy	Horsepower Average
Radial drills, 3-foot arm.	3	1 to 2
Radial drills, 4-foot arm.	5 to 7½	2 to 3
Radial drills, 5 to 6 and 7-foot arm.	5 to 7½	3 to 5
Radial drills, 8 to 9 and 10-foot arm.	7½ to 10	5 to 7½

CYLINDER BORING MACHINES

Motor—A, B, or C

Dia. of Spindle Inches	Max. Boring Dia., Inches	H.P.
4	20	7½
6	30	10
8	40	15

Pipe Threading and Cutting-Off Machines

Motor—A, B, or C

Size Pipe—Inches	H.P.
¼ to 2	2
½ to 3	3
1 to 4	3
1¼ to 6	3 to 5
2 to 8	3 to 5
3 to 10	5
4 to 12	5
8 to 18	7½
24	10

PLANERS

Motor—A*, B*, or C

Width—Inches	Distance Under Rail—Inches	H.P.
22	22	3
24	24	3 to 5
27	27	3 to 5
30	30	5 to 7½
36	36	10 to 15
42	42	15 to 20
48	48	15 to 20
54	54	20 to 25
60	60	20 to 25
72	72	25 to 30
84	84	30
100	100	40

Normal length of bed in feet is about ¼ the width in inches.

*Compound-wound motor.

Rotary Planers

Motor—A, B, or C

Dia. of Cutter—Inches	H.P.
24	5
30	7½
36 to 42	10
48 to 54	15
60	20
72	25
84	30
96 to 100	40

HYDROSTATIC WHEEL PRESSES

Motor—B or C

Size—Tons	H. P.
100	5
200	7½
300	7½
400	10
600	15

PUNCHING AND SHEARING MACHINES

Presses for notching sheet iron, motor—A, B, or C, ½ to 3 horsepower

Punches

Motor—B* or C†

Dia.—Inches	Thickness—Inches	H. P.
⅜	¼	1
½	½	2 to 3
⅝	⅝	2 to 3
¾	¾	3 to 5
⅞	¾	5
1	½	5
1	1	7½
1¼	1	7½ to 10
1¾	1	10 to 15
2	1	10 to 15
2½	1½	15 to 25

*Compound-wound motor.

†Wound secondary or squirrel-cage motor with approximately 10 per cent slip on the larger sizes.

Shears

Motor—B* or C†

Width—Inches	Horsepower Cut ⅛-Inch Iron	Horsepower Cut ¼-Inch Iron
30 to 42	3	5
50 to 60	4	7½
72 to 96	5	10

Bolt shears. . . . . 7½ horsepower

Double-angle shears. . . . . .10 horsepower

*Compound-wound motor.

†Wound secondary or squirrel-cage induction motor with 10 per cent slip.

Lever Shears

Motor—B* or C†

Size—Inches	H.P.
1 x 1	5
1½ x 1½	7½
2 x 2	10
6 x 1	
2½ x 2½	15
1 x 7	
2¾ x 2¾	20
1½ x 8	
3½ x 3½	30
4½ round	

*Compound-wound motor.

†Wound secondary or squirrel-cage motor with approximately 10 per cent slip.

Plate Shears

Motor—B* or C†

Size of Metal Cut Inches	Cut Per Min.	Length of Stroke Inches	H.P.
⅜ x 24	35	3	10
1 x 24	20	3	15
2 x 14	15	4¼	30
1 x 42	20	4	20
1½ x 42	15	4½	60
1¼ x 54	18	6	75
1½ x 72	20	5½	10
1¼ x 100	10 to 12	7½	75

*Compound-wound motor.

†Wound secondary or squirrel-cage motor with approximately 10 per cent slip.

Tin Plate Squaring Shears

Motor—B or C

Size of Plates—Inches	Cuts Per Min.	H.P.
54 x 54 3/16 packs	30	7½
72 x 72 3/16 packs	30	7½

SHAPERS

Motor—A, B, or C

Stroke—Inches	H.P. Single Head
12 to 16	2
18	2 to 3
20 to 24	3 to 5
30	5 to 7½

Traverse Head Shaper

20	7½
24	10

ROLLS—BENDING AND STRAIGHTENING

Motor—B* or C†

Width—Feet	Thickness—Inches	H.P.
4	⅜	5
6	5/16	5
6	7/16	7½
6	¾	15
8	⅞	25
10	1⅛	35
10	1½	50
24	1	50

*Standard bending roll motor.
†Wound secondary induction motor.

SAWS—COLD AND CUT OFF

Motor—A, B, or C

Size of Saw—Inches	H.P.
20	3
26	5
32	7½
36	10 to 15
42	20
48	25

SLOTTING AND KEY SEATING

Motor—A, B, or C

Stroke—Inches	H.P.
6	3
8	3 to 5
10	5
12	5
14	5 to 7½
16	7½
18	7½ to 10
20	10 to 15
24	10 to 15
30	10 to 15

HORIZONTAL BORING, DRILLING AND MILLING MACHINES

Motor—A, B, or C

Size of Spindle Inches	Horsepower for Single Spindle
3½ to 4½	5 to 7½
4½ to 5½	7½ to 10
5½ to 6½	10 to 15

For machines with double spindles use motors of double the horsepower given.

MULTIPLE SPINDLE DRILL

Motor—A, B, or C

Size of Drills Inches	Up to	H.P.
1/32 to ¼	6 to 10 spindle	3
1/16 to ⅜	10	5
3/16 to ½	10	7½
¼ to ¾	10	10
⅜ to 1	10	10 to 15
2	4	7½
2	6	10
2	8	15

EMERY WHEELS, GRINDERS, ETC.

Motor—B or C

Wheels No.	Size—Inches	H.P.
2	6	½ to 1
2	10	2
2	12	3
2	18	5 to 7½
2	24	7½ to 10
2	26	7½ to 10

MISCELLANEOUS GRINDERS

Motor—B or C

	H.P.
Wet tool grinder	2 to 3
Flexible swinging, grinding, and polishing machine	3
Angle cock grinder	3
Piston rod grinder	3
Twist-drill grinder	2
Automatic tool grinder	3 to 5

GRINDING MACHINES (GRINDING SHAFTS, ETC.)

Motor—A, B, or C

Dia. Wheel Inches	Length Work Inches	Horsepower Average Work	Horsepower Heavy Work
10	50	5	7½
10	72	5	7½
10	96	5	7½
10	120	5	7½
14	72	10	15
18	120	10	15
18	144	10	15
18	168	10	15

GEAR CUTTERS

Motor—A, B, or C

Size—Inches	H.P.
36 x 9	2 to 3
48 x 10	3 to 5
30 x 12	5 to 7½
60 x 12	5 to 7½
72 x 14	7½ to 10
64 x 20	10 to 15

HAMMERS

Motor—B* or C†

Size—Lbs.	H.P.
15 to 75	½ to 5
100 to 200	5 to 7½

Bliss drop hammers require approximately 1 horsepower for every 100-lb. weight of hammer head.

*Compound-wound motor.

†Wound secondary squirrel-cage motor with approximately 10 per cent slip.

LATHES

Motor—A, B, or C

Engine Lathes

Swing—Inches	Horsepower Average	Horsepower Heavy
12	½	2
14	¾ to 1	2 to 3
16	1 to 2	2 to 3
18	2 to 3	3 to 5
20 to 22	3	7½ to 10
24 to 27	5	7½ to 10
30	5 to 7½	7½ to 10
32 to 36	7½ to 10	10 to 15
38 to 42	10 to 15	15 to 20
48 to 54	15 to 20	20 to 25
60 to 84	20 to 25	25 to 30

Axle Lathes

	H.P.
Single	5, 7½, 10
Double	10, 15, 20

Wheel Lathes

Size—Inches	H.P.	Tail Stock Motor* H.P.
48	15 to 20	5
51 to 60	15 to 20	5
79 to 84	25 to 30	5
90	30 to 40	5 to 7½
100	40 to 50	5 to 7½

*Standard machine-tool traverse motor.

MILLING MACHINES

Motor—A, B, or C

Vertical Slabbing Machines

Width of Work—Inches	H.P.
24	7½
32 to 36	10
42	15

Vertical Milling Machines

Height Under Work—Inches	H.P.
12	5
14	7½
18	10
20	15
24	20

Plain Milling Machines

Table Feed Inches	Cross Feed Inches	Vertical Feed Inches	H.P.
34	10	20	7½
42	12	20	10
50	12	21	15

Universal Milling Machines

Machine No.	H.P.
1	1 to 2
1½	1 to 2
2	3 to 5
3	5 to 7½
4	7½ to 10
5	10 to 15

Horizontal Slab Millers

Width Between Housings Inches	Horsepower	
	Average	Heavy
24	7½ to 10	10 to 15
30	7½ to 10	10 to 15
36	10 to 15	20 to 25
60	25	50 to 60
72	25	75

METHOD OF ESTIMATING H. P. TO TAKE A GIVEN CUT ON LATHES AND OTHER TOOLS USING THE ROUND NOSE TYPE OF TOOL

To determine the h. p. required to remove metal, the cubic inches of metal removed per minute are multiplied by a constant.

The rate of removing metal can be determined by the aid of Fig. 63; the figures in the vertical column at the left represent areas of cut and those in the bottom horizontal row are cutting speeds in feet per minute. The figures on the oblique lines are cubic inches of metal removed per minute. An example will illustrate the use of the diagram:

Cutting speed—60 ft. per minute.

Area of cut—.015 sq. in. ($\frac{1}{16}$-in. feed, ¼-in. cut).

The intersection of the horizontal line through .015 and the vertical line through 60 is on oblique line 11; i. e., 11 cubic inches of metal are removed per minute.

The following constants based on average shop conditions are useful for estimating purposes when round nose lathe type tools are used:

Cast iron, 0.3 to 0.5 h. p. per cu. in. per min.

Wrought iron, machinery steel, 0.6 h. p. per cu. in. per min.

Steel—50 carbon and harder, 1.00-1.25 h. p. per cu. in. per min.

Brass and similar alloys, 0.2 to 0.25 h. p. per cu. in. per min.

For the average work of drills the h. p. is estimated in a similar way. The cubic inches per minute are calculated by the formula $Q = .7854 \times \mathbf{d}^2\mathbf{f}$ where $\mathbf{d}$ is the diameter of the drill in inches and $\mathbf{f}$ the feed in inches per minute. The constants are approximately double those given above.

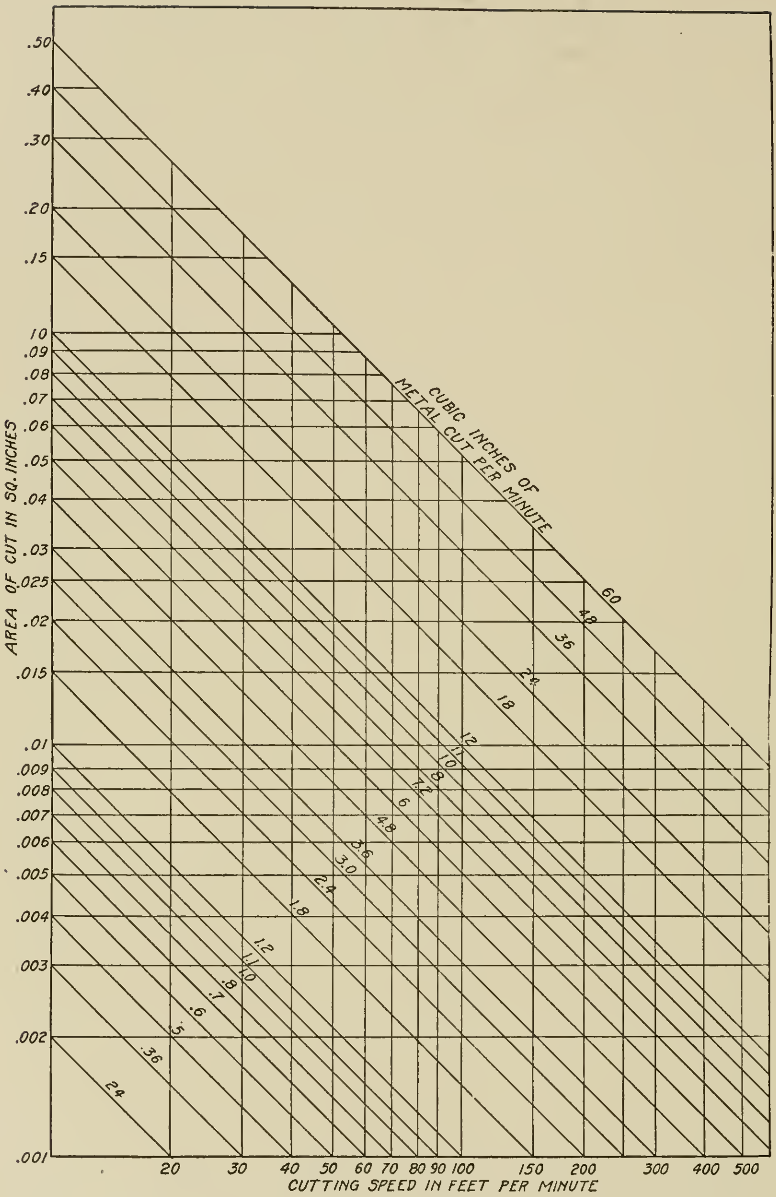


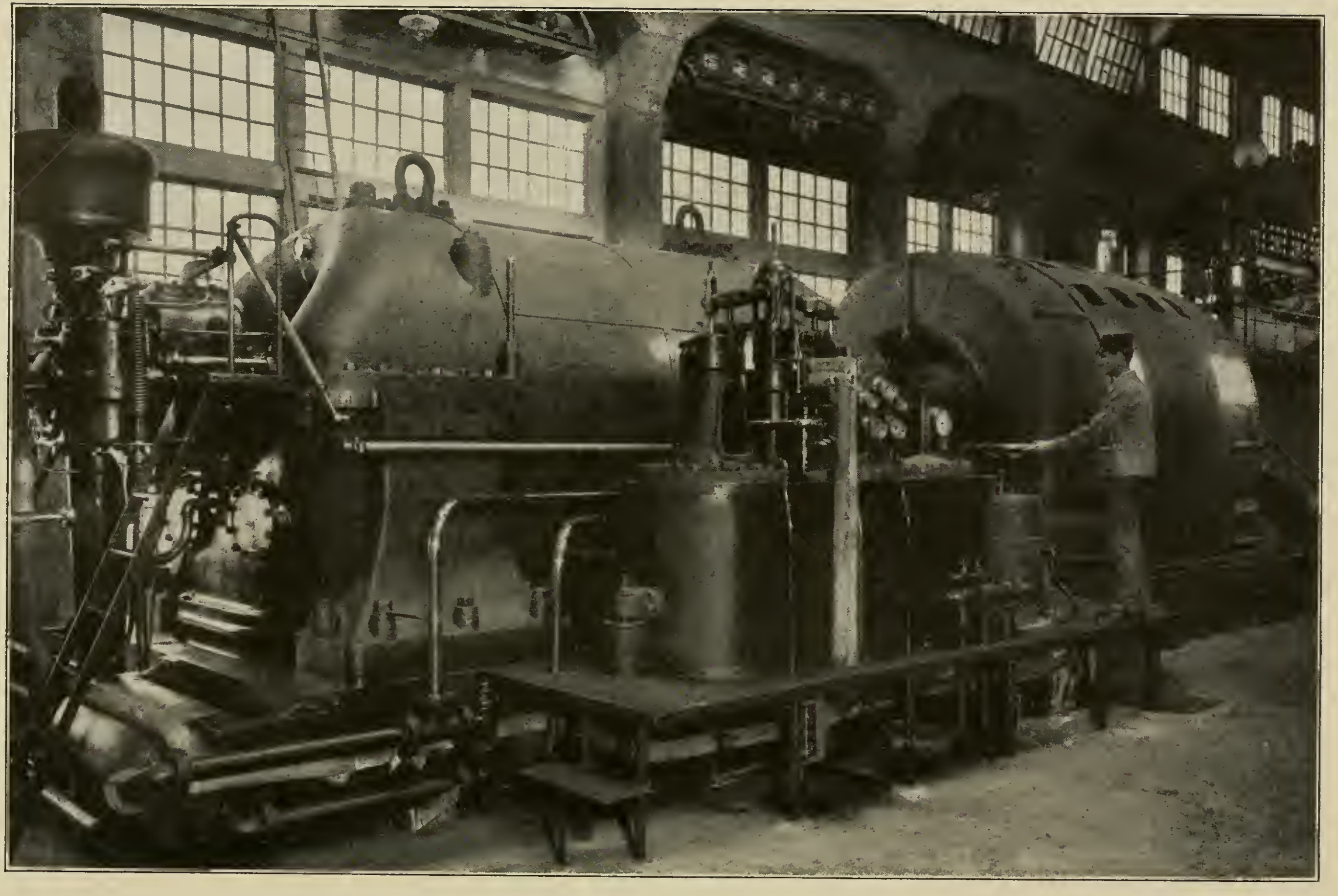
Fig. 63. Diagram Showing Method of Determining Rate of Making Cuts in Lathe Work

TABLE II

Engineering Information—Chain Data

Standard Sizes, Weights, Wheel Widths, Working Loads, and Horsepowers

Pitch	WIDTH		Weight per foot Lbs.	Wheel Width Flanged or not Inches	Working Load Lbs.	HORSEPOWERS AT VARIOUS SPEEDS				
	Nominal Over Link Inches	Total Outside Inches				700 ft. per min.	800 ft. per min.	900 ft. per min.	1100 ft. per min.	1200 ft. per min.
½ Inch	.25	.36	.24	¾	12	.25	.29	.32	.4	.43
	.5	.62	.48	1	24	.51	.58	.65	.8	.87
	.75	.87	.69	1¼	36	.76	.87	.98	1.2	1.31
	1.0	1.12	.90	1½	48	1.01	1.16	1.30	1.6	1.74
	1.25	1.39	1.11	1¾	60	1.27	1.46	1.64	2.0	2.18
	1.5	1.64	1.32	2	72	1.53	1.74	1.96	2.4	2.62
	2.0	2.14	1.80	2½	96	2.02	2.32	2.60	3.2	3.48
	3.0	3.14	2.70	3½	144	3.03	3.48	3.90	4.80	5.22
⅝ Inch	.75	.9	.9	1¼	57	1.21	1.38	1.56	1.9	2.08
	1.0	1.15	1.15	1½	76	1.61	1.84	2.07	2.53	2.76
	1.25	1.4	1.4	1¾	95	2.02	2.30	2.60	3.17	3.46
	1.5	1.68	1.65	2 3/16	114	2.42	2.76	3.11	3.8	4.15
	1.75	1.93	1.9	2 7/16	133	2.82	3.22	3.63	4.43	4.80
	2.0	2.18	2.15	2 11/16	152	3.22	3.68	4.15	5.17	5.51
	3.0	3.18	3.30	3 11/16	228	4.83	5.52	6.21	7.56	8.30
¾ Inch	.75	.93	1.2	1 7/16	70	1.48	1.70	1.91	2.34	2.55
	1.0	1.18	1.5	1 11/16	94	1.99	2.28	2.56	3.13	3.42
	1.25	1.43	1.8	1 15/16	117	2.48	2.84	3.19	3.9	4.25
	1.5	1.68	2.1	2 3/16	141	2.99	3.42	3.85	4.7	5.12
	1.75	1.97	2.4	2½	164	3.48	3.98	4.47	5.5	5.96
	2.0	2.21	2.7	2¾	188	3.99	4.56	5.14	6.27	6.84
	3.0	3.21	3.9	3¾	282	6.00	6.84	7.70	9.40	10.20
	2.5	2.68	3.6	2 15/16	211	4.98	5.70	6.41	7.83	8.54
	4.0	4.21	5.4	4¾	376	7.98	9.12	10.28	12.54	13.68
1 Inch	1.0		1.8	1 9/16	158	3.35	3.83	4.31	5.27	5.74
	1.5		2.6	2 1/16	237	5.04	5.75	6.48	7.9	8.64
	2.0		3.4	2 11/16	316	6.71	7.56	8.62	10.5	11.50
	2.5		4.2	3 3/16	395	8.39	9.58	10.80	13.15	14.4
	3.0		5.0	3 11/16	474	10.05	11.5	12.9	15.8	17.25
	4.0		6.8	4 11/16	632	13.42	15.12	17.24	21.0	23.0
	5.0		8.4	5 11/16	790	16.78	19.16	21.64	26.3	28.8
1¼ Inch	1.5		3.2	2⅛	316	6.7	7.66	8.61	10.5	11.50
	2.0		4.2	2⅝	422	8.9	10.2	11.50	14.0	15.3
	2.5		5.2	3⅛	527	11.2	12.8	14.4	17.6	19.2
	3.0		6.2	3¾	633	13.45	15.36	17.3	21.1	23.0
	4.0		8.2	4¾	844	17.9	20.4	23.0	28.2	30.7
	5.0		10.2	5¾	1055	22.4	25.6	28.8	35.2	38.4
	6.0		12.4	6¾	1266	26.9	30.72	34.6	42.2	46.0
1½ Inch	2.0		4.9	2¾	607	12.9	14.7	16.6	20.2	22.1
	3.0		7.3	3¾	911	19.35	22.1	24.9	30.3	33.1
	4.0		9.7	4⅞	1214	25.75	29.4	33.1	40.5	44.2
	5.0		12.1	5⅞	1518	32.2	36.8	41.4	50.3	55.2
	6.0		14.6	6⅞	1822	38.7	44.2	49.8	60.6	66.2
1¾ Inch	6.0		16.0	7½	2250	47.75	54.52	61.4	75.0	81.9
	8.0		22.0	9½	3000	63.6	72.75	81.9	100.0	109.0
	10.0		27.0	11½	3750	79.6	91.0	102.25	125.0	136.3
	12.0		32.0	13½	4500	95.5	109.04	122.8	150.0	163.8
2 Inch	4.0		12.9	5½	1650	35.0	40.0	45.0	55.0	60.0
	6.0		19.2	7½	2500	53.0	60.6	68.2	83.5	91.0
	8.0		25.4	9½	3300	70.0	80.0	90.0	110.0	120.0
	9.0		28.33	10½	3750	79.6	91.0	102.25	125.0	136.3
	10.0		32.0	11½	4166	88.5	101.0	113.70	139.0	151.5
	12.0		37.5	13½	5000	106.0	121.2	136.4	167.0	182.0



WESTINGHOUSE TURBO-GENERATOR INSTALLED FOR CITY ELECTRIC COMPANY, SAN FRANCISCO, CALIFORNIA

The turbine is of the high-pressure, semi-double flow type. Generator is of 10,000-kilowatt capacity, 11,000 volts, three-phase and 1800 r. p. m.

Courtesy of Westinghouse Machine Company

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY

PART I

The object of this treatise is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (d.c.) and alternating-current (a.c.) generators and motors are treated elsewhere. The subject may be divided into three parts, as follows:

(1) Selection, Erection, Connection, and Operation
(2) Inspection and Testing
(3) Troubles, or ''Diseases,'' and Remedies.

THE MACHINE—FROM SELECTION TO SERVICE

SELECTION OF A MACHINE

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. The construction should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by a machine depends in a great measure on the kind of machine. Direct-connected revolving-field a.c. generators, revolving-field synchronous motors, and induction motors require little or no attention, whereas machines of the commutating type demand a certain amount of care to keep brushes and commutators in condition. Above all, cleanliness is essential to the life and proper operation of all electrical apparatus.

Handling. Machines of the revolving-field alternating-current type are arranged so that the armatures may be moved on the foundation plates parallel to the shaft to allow of repairs to either field or armatures. Direct-current types of machines are usually split through the magnet frame in a horizontal plane so that they may be disassembled readily.

Regulation. Unless the machine is self-regulating, it is usually customary to employ some automatic device external to the machine to maintain constant voltage.

Form. Preferably the machine should be of standard reliable make, to insure proper symmetry of form as well as ruggedness of design.

Capacity. A machine should be carefully selected for the work it has to perform, the highest efficiency being obtained at normal and slight overloads. The heating at normal and prescribed overloads is fixed by the Standardization Rules of the American Institute of Electrical Engineers.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and the workmanship required for the construction of a high-grade electrical machine are costly.

ERECTION

MECHANICAL CONDITIONS

Location. The place chosen for the machine should, if possible, be *dry, free from dust or grit, light, and well ventilated.* It should also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and well managed, the vibrations occurring on a poor foundation will produce noise, sparking at the brushes, and other troubles.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation, Fig. 1. The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper positions for them being determined by a wood template suspended above the foundation, as shown in Fig. 2. The bolts are preferably surrounded by iron pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar. Lime mortar is entirely unfit for the purpose,* being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of cement. This forms a level surface upon which to set the

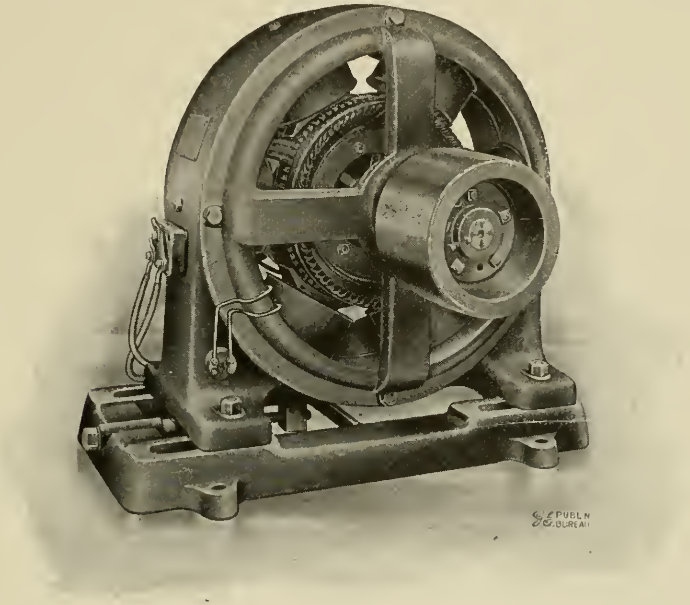


Fig. 1. General Electric Belted Generator Showing Adjustable Base

machinery. Almost all large foundations are concrete, brick seldom being used.

Fixing the Machine. *Levelling.* In fixing either direct-connected or belt-driven machines, determine, with a long straight edge and spirit level, checked by a surveyor's Y level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts.

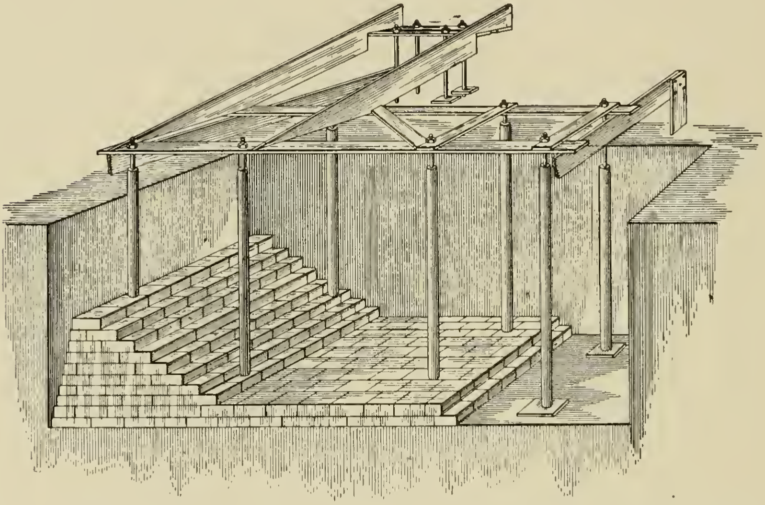


Fig. 2. Diagram of Power House Foundation Showing Wood Template Suspended above Foundation for Construction Purposes

Aligning. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or flywheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast iron or other wedges; and the generator frame also should be adjusted to its proper height by means of thin strips of metal set between its supporting feet and the bed-plate.

Grouting the Base. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wood battens around the bed-plates of the machine, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen at least one-half inch above the under side of the bed-plate. This head of grouting allows for shrinkage as the water dries and the grouting settles. If grouting were poured only to the under side of the bed-plate, it would shrink away when dry and leave a space between the foundation and the bed-plate. When the cement has partially set, the wall may be taken down and the surplus cement removed. When the cement is dry, the nuts on the holding-down bolts may be drawn up. This fixes the machine firmly upon its foundation.

Mechanical Connections

Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection
Belting
Rope Driving
Toothed Gearing

Other apparatus, such as shafting, clutches, hangers, and pulleys, are used in combination with the above means.

Direct Connection. Direct connection is the simplest and, for that and other reasons, the most desirable means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This method, also called direct coupling or direct driving, compels the engine and the generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of a reciprocating engine is low; hence to obtain the same voltage from a direct-connected generator, more conductors are necessary, or the flux cut must be increased. Accordingly, the armature and the frame of the direct-connected generator must be larger, thus making it more expensive than a belt-driven machine. On the other hand the speed of steam turbines is so high that it usually requires specially designed and constructed generators for direct connection.

Continuous Shaft for Engine and Generator. The direct connection of an engine and generator is accomplished in several ways, the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents a three-bearing belted generator.

Coupled Shafts. Another form of direct coupling is that in which a motor and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable.

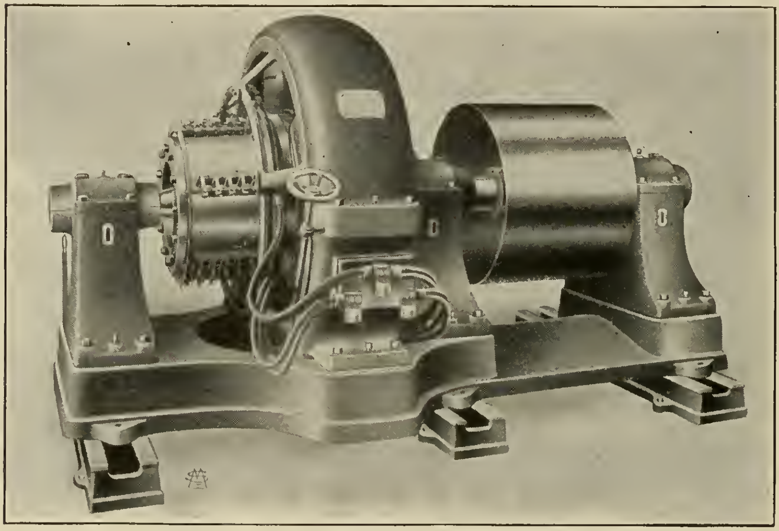


Fig. 3. Fort Wayne Three-Bearing Belted Generator.

In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling, one form having rubber cylinders interposed between the two parts.

The direct coupling of generators with hydraulic turbines can usually be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive as well as noiseless action* of direct connection have caused it to become the most approved method.

Belting. *Kind.* If the generator or motor is not directly connected—the former to the prime mover, the latter to the apparatus to be driven—it is usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc., and it may be leather, rawhide, rubber, or rope. For the ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well, because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting: single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the ''light-double'' belting is usually the best.

Power Transmitted by Belt. The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that ''single'' belt will transmit one horsepower for each inch of its width when traveling at a speed of 1000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. This statement of h. p. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180 degrees, which is usually the case. If the arc of contact is less than 180 degrees, the power transmitted is less in the following proportion: An arc of 135 degrees gives 84 per cent, while 90 degrees contact gives only 64 per cent of the power derived from a belt contact of 180 degrees. If, on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top.* If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

An approximate expression for determining the width of a single belt required to transmit a given horsepower is as follows:

$$W = \frac{\text{h.p.} \times 1000}{S \times C}$$

in which W is the width of the belt in inches; h. p. the horsepower to be transmitted; S is the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute; and C is a factor dependent upon the arc of contact.*

"Double" belting is expected to transmit $1\frac{1}{2}$, and "light-double" $1\frac{1}{4}$ times as much power as "single" belting of the same width. Belting formulas are only approximate and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature, and moisture. The smooth side of a belt should always be run against a pulley, as it transmits more power and is more durable.

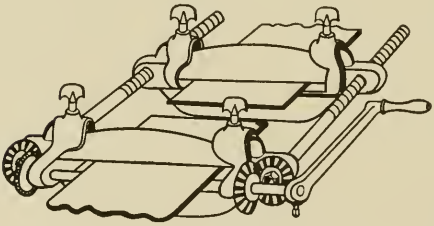


Fig. 4. Belt Clamp for Splicing

Spliced Joints. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints temporarily. A spliced or "endless" joint is made as follows: The two ends of the belt are pared down on opposite sides with a sharp knife into the form of long thin wedges, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself.* The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp, Fig. 4, should be employed.

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* Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as one-half inch per foot of length.

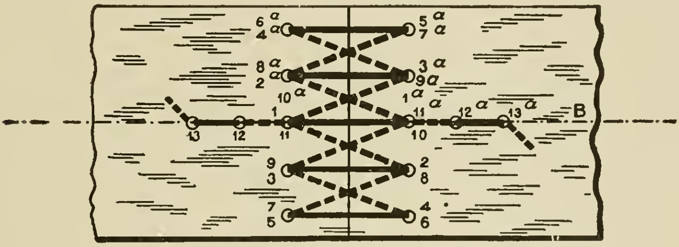


Fig. 5. Diagram Showing Proper Way of Lacing Belt

Laced Joints. The lacing of a belt is a very simple and common method of making a joint; but it should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration, and sparking; with lighting generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift sidewise, owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 5. The various holes should be made with a circular punch, the nearest one being about three-fourths inch from the side, and the line through the center of the row of holes about one inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire should be used. The lacing is doubled to find its middle; and the ends are passed through the two holes marked *1* and *1a,* precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a, 3a, 4a,* etc., finishing at *13* and *13a,* which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side parallel to the direction of motion.

Arrangement and Care of Belting. It is desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between centers of two belt-connected pulleys should, if possible, be not less than three times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the faces of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly ''lined up,'' in which case one or both machines should be slightly shifted, until the belt runs true. If possible, the machine and the belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings. Where it is impracticable to have sufficient distance between centers of belt-connected pulleys, an idler pulley is often used to give greater arc of contact and elastic tension.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.,—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing, it is advisable to surround it by a railing or box.

Rope Driving. Rope driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a good grip by a sort of wedging action. The kinds of rope ordinarily employed for this purpose are cotton, hemp, rawhide, and wire.

Advantages. The general advantages are as follows:

(1) Economy in first cost.

(2) Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

(3) It is almost noiseless.

(4) Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter. The breaking strength varies from 7000 to 12,000 pounds per square inch of cross section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

Power Transmitted by Rope Drive. The diameter of a single rope necessary to transmit a required h.p. is given by the formula:

$$D^2 = \frac{825 \text{ h.p.}}{V\left(200 - \frac{V^2}{1072}\right)}$$

in which h.p. is horsepower transmitted; V is velocity of rope in feet per second; and D is diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension ($200\ D^2$ pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which

Table I

Horsepower Transmitted by Cold-Rolled Shafting at Various Speeds

$$\text{h.p.} = \frac{R\,d^3}{100}$$ in which R is revolutions per minute and d is diameter of shaft in inches.

DIAMETER IN INCHES	REVOLUTIONS PER MINUTE			
	100	200	300	400
$1\frac{1}{2}$	3.4	6.7	10	13.5
$1\frac{5}{8}$	4.3	8.6	12.8	17
$1\frac{3}{4}$	5.4	10.6	16	21
$1\frac{15}{16}$	7.3	14.5	22	29
2	8	16	24	31.9
$2\frac{1}{8}$	9.6	19.1	29	38
$2\frac{1}{4}$	11.4	23	34	45
3	27	54	81	108
$3\frac{1}{4}$	34	68	103	136
$3\frac{1}{2}$	43	86	129	171
4	64	128	192	255
5	125	250	375	500

For h.p. transmitted by turned-steel shafting multiply above figures by 0.8.

For ordinary line shafting with supporting bearings about 8 feet apart—multiply by 1.43 for cold-rolled and by 1.11 for turned shafts.

Usual speed of shafting:

Machine Shops	120 to 250 r.p.m.
Wood Shops	250 to 300 r.p.m.
Textile Mills	300 to 400 r.p.m.

passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley and, if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing. Toothed gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. The most extensive applications of gearing for electrical purposes are in connection with railway motors, and many industrial applications of a. c. and d. c. motors.

Shafting. An intermediate or countershaft is not desirable since it increases the complication and the frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned". The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth hard surface, but it is difficult to make it perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can easily be made on it. Table I gives the ordinary data for shafting.

ASSEMBLING OF THE MACHINE

Numbers of Parts and Drawings the Guide. The proper method of setting the foundation plate, or base, of a machine has already been described. The successive parts of the machine should then be assembled in their respective order. The bearing pedestals will usually be found to have a number stamped on them with a corresponding number stamped on the base. The same is true for the magnet frame. Approved drawings showing the correct mechanical assembly and proper electrical connection should be furnished with each machine.

Care of Windings. In handling the parts of the machine, care must be used not to damage the windings in any way. In the case of a direct-current machine, the commutator must be properly protected. If the machine is assembled by means of a crane, the lifting cable should not come in contact with any part of the windings. Often a wood spreader, Fig. 6, between turns of the cable is necessary to keep it clear of the windings.

Attention to Joints and Metal Surfaces. All magnetic joints must be made clean and bright. A very light coating of oil will prevent such joints from rusting. The same precaution should apply to all finished surfaces about the machine. The bearings should be carefully examined to see that their bearing surfaces have not been bruised or roughened. Should such defects show up, the bearings should be scraped by an *experienced machinist.* If the bearing surface of the shaft has become bruised or pitted by rust, this should be carefully smoothed before assembling the shaft in the bearings. The oil bearings should be flushed out with gasoline or some light grade of oil before being filled with a good grade of dynamo oil. The field frame should be set so as to obtain a uniform air gap all around.

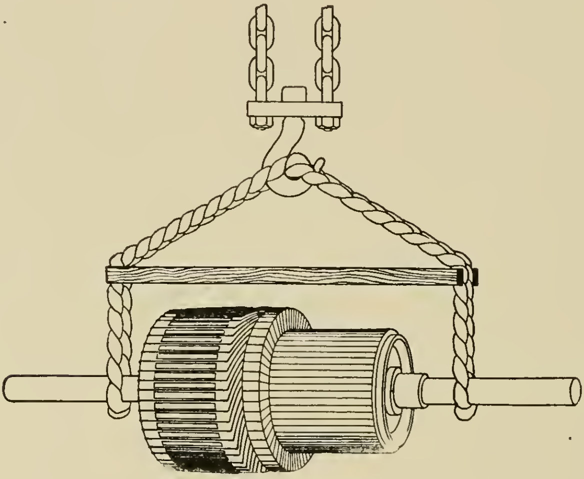


Fig. 6. Proper Rigging for Handling Armature Showing Wood Spreader to Protect Windings

Brushes and Commutator on D.C. Machines. In the case of a direct-current machine the accurate spacing and setting of the brushes on the commutator is essential to good commutation. Brushes should be fitted to the commutator by drawing a piece of sandpaper under them; then they should be spaced around the commutator by laying off on a thin steel tape or a piece of paper equidistant positions corresponding to the number of poles on the machine. The steel tape is placed around the commutator and either the heel or toe of the brushes on each brush stud made to conform to the marking on the tape. At the same time the brushes of each set must be placed on the commutator parallel to the commutator bars.

Examination Before Starting. Before starting a machine it should be carefully examined to see that there are no loose pieces of metal or other material about the machine. See that the bearings are filled with oil to the proper level. If the machine is belt driven, see that the belt has the proper tension.

Starting a Generator. *Gradual Building-Up of Speed.* In the case of a generator direct-connected to the prime mover, bring up the speed of the set gradually. Be sure that everything is running smoothly and that the oil rings in the self-oiling bearings are turning. The speed may finally be brought up to normal. If it has been determined by insulation test that the machine requires no drying out, the voltage may be built up to normal gradually, and the machine will be ready for regular service.

Drying Out. Large direct-current generators often require drying out before putting in service. This may be accomplished by short circuiting the armature leads beyond the ammeter and "bucking" the shunt and series fields. In the case of an alternator, the phases may be short circuited on the outside of the switchboard instruments so that a reading may be obtained. The field will require very slight excitation to produce full load current with phases short circuited.

Insulation Resistance Test. The insulation resistance should be measured and, if this is found to be the proper amount for the machine under consideration, it may be put into service. If no direct reading instrument is obtainable, the resistance may be measured by using a direct-current voltmeter of known high resistance on a 500 volt direct-current circuit. The method is as follows:

Using a constant potential of about 500 volts, the voltage reading is determined by connecting the terminals of the supply circuit directly to the meter. The insulation resistance to be measured is then connected in series with the voltmeter and a second reading is made and noted. The resistance X is then given by the formula

$$\frac{R_m}{R_m+X}=\frac{D_m}{V}$$

or

$$R_m + X = \frac{VR_m}{D_m}$$

$$\therefore \quad X = \frac{VR_m}{D_m} - R_m$$

in which R_m is resistance of voltmeter; D_m is deflection of voltmeter with resistance in series; V is voltage of the supply system when reading D_m; and X is resistance sought.

TYPICAL WIRING CONNECTIONS

DIRECT-CURRENT GENERATORS

Shunt Type, Supplying Constant-Potential Circuit. A shunt type d. c. generator is represented in Fig. 7, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils Sh through a resistance-box R, to regulate the strength of the current and, therefore, the magnetism in the field. A voltmeter also is connected to the two brushes or main conductors to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamp L, or motor M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

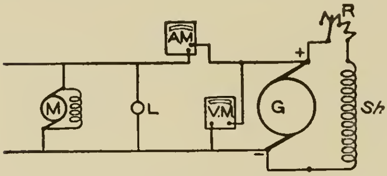
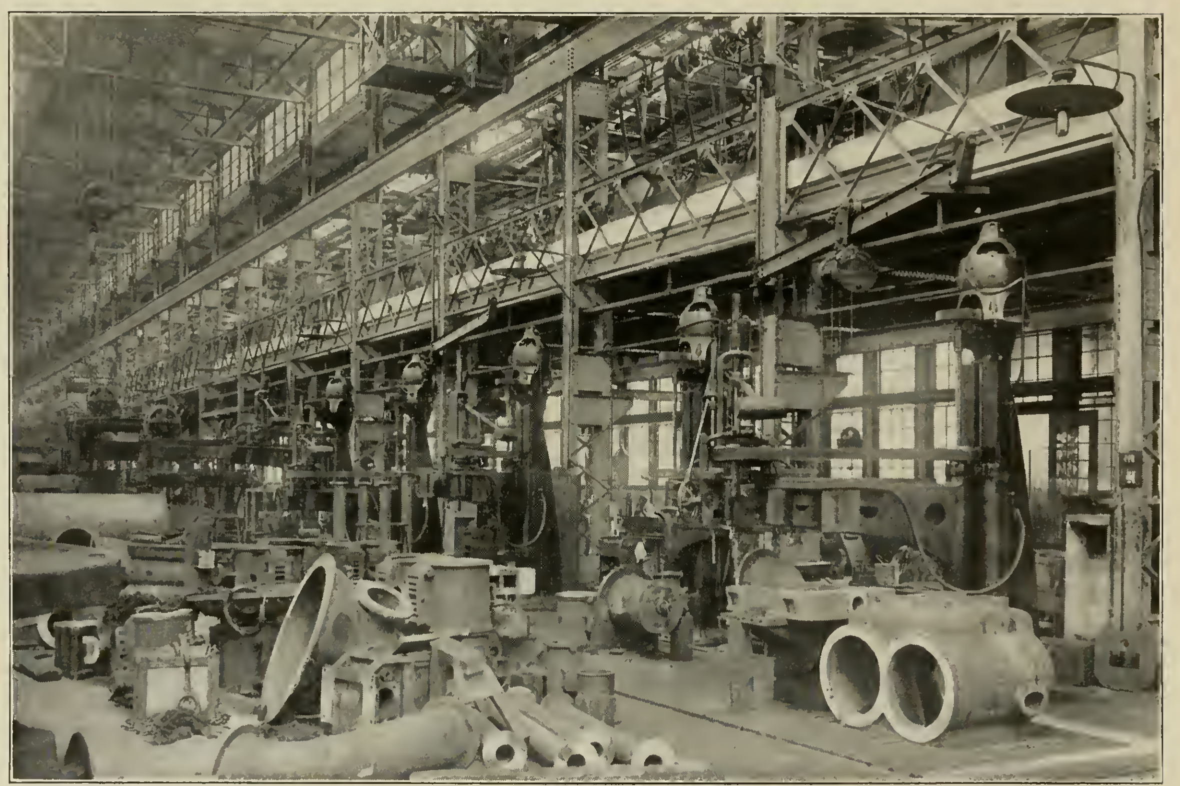


Fig. 7. Diagram for Connecting Shunt Type of D. C. Generator

Series Type. In a series-wound dynamo, the winding on the field being in series with the armature, the number of ampere turns in the field varies with the load on the machine or the amount of current flowing.

The field is wound with relatively few turns of large wire capable of carrying the full armature current. The voltage of a



SHOP INSTALLATION OF INTER-POLE VERTICAL MOTORS DRIVING VERTICAL DRILLS

Courtesy of Electro-Dynamic Company

series generator is low at light loads, but increases rapidly as load comes on. At normal load the field approaches the saturation point. Series generators are seldom, if ever, used except for constant-current generators on some arc-lighting systems or for boosters. Fig. 8 shows a series generator in which the load, field, and armature are all in series.

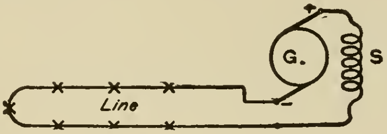


Fig. 8. Diagram for Series Generator Showing Load, Field, and Armature, All in Series

Compound Type. A compound-wound generator has two sets of field windings—a shunt winding and a series winding—and is therefore a combination of the two preceding types, Fig. 9. At no load and light load the shunt field *Sh* is excited to give normal voltage. The series winding *S* is connected to assist the shunt field so that, as the load comes on and a larger current passes through the series field, the drop in voltage which would otherwise occur is prevented. The voltage at no load is adjusted by means of the rheostat *R* in series with the shunt field. As the load comes on, the voltage is automatically regulated by the action of the series field. The voltage may be held practically constant from no load to full load or it may be increased at full load to 10 per cent or 15 per cent above the no-load value. This is the usual practice in generators for railway work and is called "overcompounding."

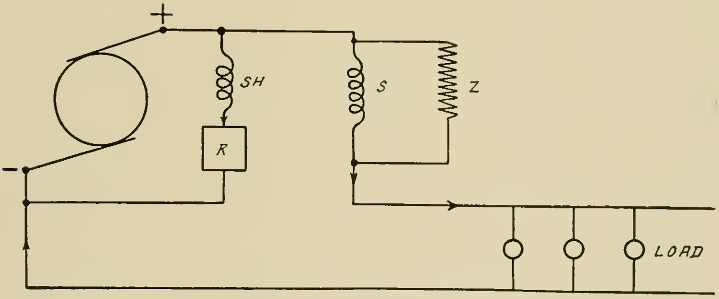


Fig. 9. Diagram for Compound-Wound Generator

The adjustment of the compounding is obtained by connecting a resistance *Z,* known as a series-field shunt, across the terminals of the series field. The relative value of the resistance of the series field and its shunt resistance determines the current in the series field, and by adjusting the shunt resistance any desired value of compounding may be obtained.

Direct-Current Generators in Parallel. Successful parallel operation of direct-current generators requires that corresponding polarities be connected together. The currents of the various generators will be added and may have different values, but the voltage will not be increased. At the time the machines are connected together, the voltages should be equal, to avoid any undue disturbances on the system.

Shunt-Wound Generators in Parallel. The connection of shunt-wound generators to switchboard buses is shown in Fig. 10. The machine with its main switch closed is operating on the station bus, the other generator is brought up to exactly the same voltage and its main switch is closed. The voltage on this second machine is then raised by means of the shunt-field rheostat until the generator takes its proportion of the load. Assume the two generators to be of the same rating and voltage, and each, therefore, supplying one-half the total current. If, owing to a drop in speed or any other cause, the voltage of one generator drops, more load would be thrown on the other machine. As the tendency of a shunt generator is to increase its voltage as the load decreases and decrease its voltage as the load increases, the machine that has been relieved of its load would tend to raise its voltage and would immediately take more load. Shunt generators are, therefore, well adapted to parallel operation, but they are not often used because of poor voltage regulation.

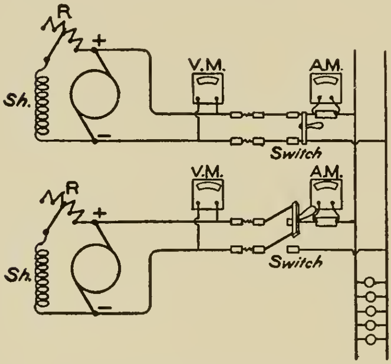


Fig. 10. Wiring Diagram for Two Shunt-Wound Generators in Parallel

Compound-Wound Generators in Parallel. A simple wiring diagram of two compound-wound generators connected in parallel is shown in Fig. 11. A is the armature; B is the series field; C is the shunt field; *D, E,* and *F* are single-pole single-throw switches; *G, H,* and *I* are buses; and *R* is the shunt-field rheostat. The switches *D* and *F* connect the main leads from the machine terminals to the main buses *G* and *I*. The switches *E* connect a point between the armature and the series field on each machine to an equalizing bus *H*.

Assume that No. 1 machine is in service and it is desired to place No. 2 machine in parallel with it. Bring No. 2 machine up to speed and adjust its voltage to about normal. Close switch *F* and switch *E*. This places the series field of No. 2 in parallel with that of No. 1 and the voltage of No. 2 will be increased. Now adjust the voltage of No. 2 by means of the field rheostat until the voltage of both machines is the same. Next close switch *D*. The load on No. 2 can now be adjusted by means of the field rheostat until the two machines are dividing the load properly.

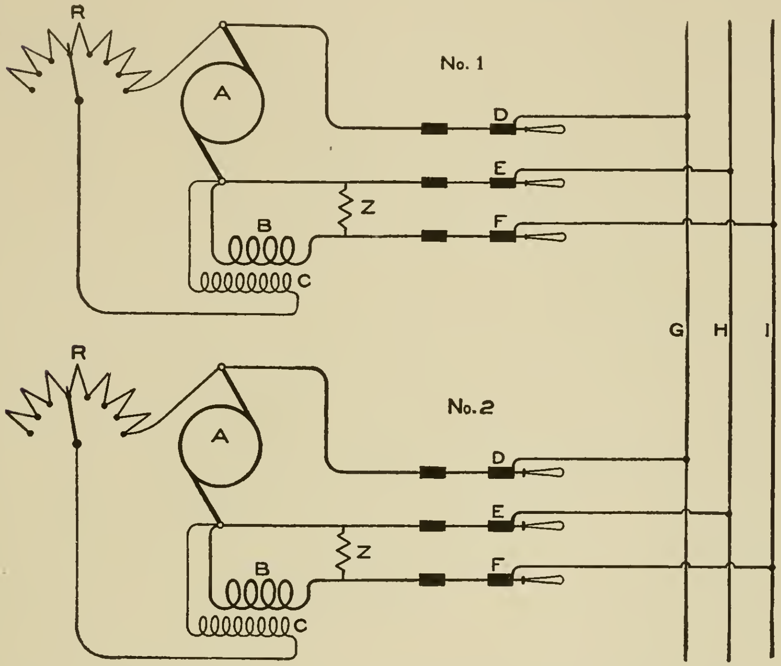


Fig. 11. Wiring Diagram for Two Compound-Wound Generators in Parallel

The voltage of the two machines can be compared in any one of several ways. A voltmeter may be connected to the buses permanently and a second voltmeter arranged to be connected to any machine by means of plugs and receptacles, or a single voltmeter can be arranged to be plugged alternately to any two machines.

On small generators the three single-pole switches are often replaced by a triple-pole switch. In this case the voltages of the running and the incoming machines are adjusted to equal value and the switch on the incoming machine is closed. The resulting sudden shift of load may not be objectionable in small machines.

Before two machines can be paralleled, it must be determined whether the compounding is the same; that is, whether the rise in voltage from no load to full load is the same. A shunt resistance, Z, Fig. 11, is placed across the series field of each machine. By changing this resistance, the amount of current in the series field and thereby the amount of the compounding can be adjusted.

When two machines are operating in parallel and one machine supplies more than its share of current, the resistance of the path through its series field coil should be increased. Since the resistance of the series field and its connection to the switchboard is low, putting a longer lead between the series field and the switchboard will usually give the desired result.

Where very large generators are used, the cost of cables to the switchboard may be considerable. In such cases the usual practice is to place the equalizer bus under the machines and as close to them as possible. The equalizer switches are then placed on a base mounted on the frame of the machine, or on a pedestal mounted beside the machine.

Direct-Current Generators in Series. The arrangement of direct-current generators in series is not very common in ordinary power work. Constant-current series-wound generators have sometimes been connected in series for arc-light service. Probably the most common example of this practice has been the use of two shunt or compound-wound generators connected in series for Edison three-wire service. At present there are a large number of stations where shunt- or compound-wound machines are operated in series in order to obtain the high voltages now common in heavy traction service.

No special connection is necessary in the machine itself to connect it in series with another. The negative of one machine is simply connected to the positive of the next one, thus adding the voltages.

Commutating-Pole Generators

Characteristics. In addition to the fundamental types of direct-current generators already described, there is the commutating-pole type of generator. This differs from the above, in mechanical respect, only in the fact that midway between each pair of main poles there is a small pole. The electrical connections differ from those of the non-commutating-pole machines only in the fact that the main current from the armature passes through the windings on the commutating poles, as well as, and in the same manner as, through the series fields already described for compound-wound generators. In the same manner the winding on the commutating poles may have a shunt across its terminals the same as the series field shunt Z shown in Fig. 9. The same remarks apply to commutating pole motors.

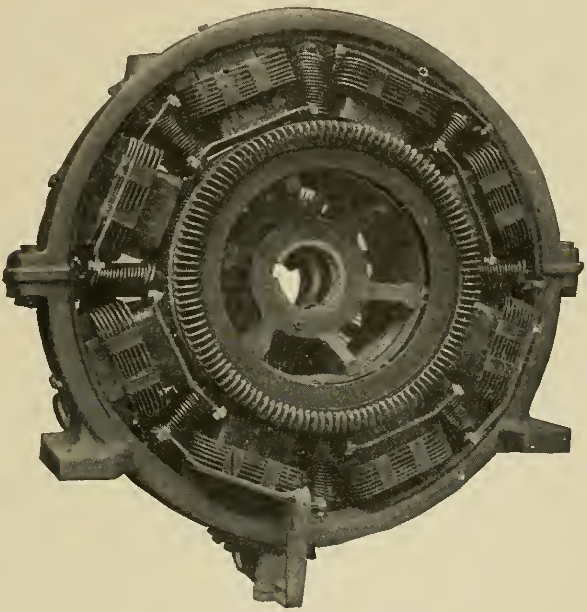


Fig. 12. Westinghouse Type Q Generator Showing Commutating Poles

The object of the commutating poles is to prevent shifting of the non-sparking position of the brushes from no load to full load. This is accomplished, because the commutating pole produces the necessary flux for neutralizing the effect of armature reaction.

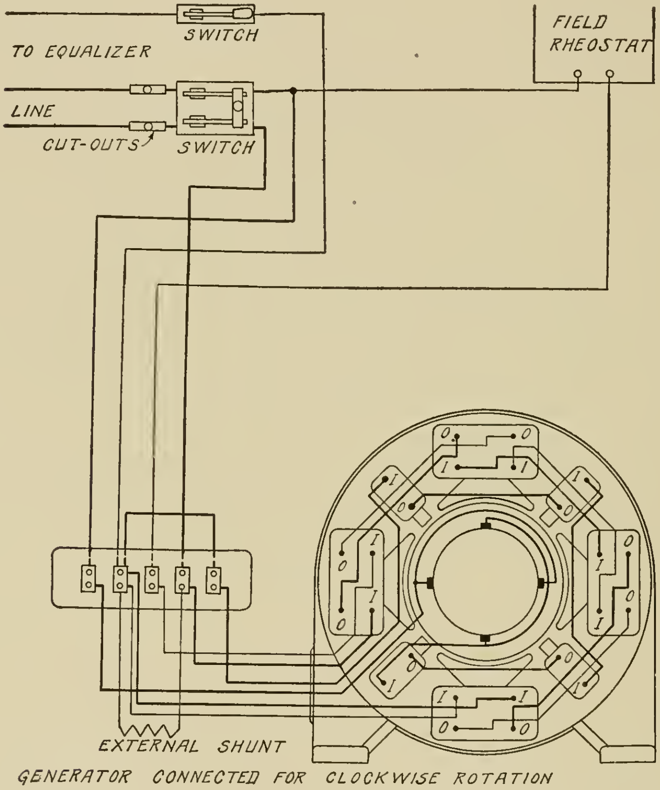


Fig. 13. Wiring Diagram for Commutating Four-Pole Compound Generator

Location of Brushes on Commutating-Pole Machines. Remove one brush from a brush holder and in its place insert a fiber brush of the same dimensions as the brush removed. Through the fiber brush bore two holes, about the size of a lead in a pencil, at such a distance apart that the holes are over the centers of two adjacent commutator bars. Insert in these holes the leads from two pencils so that the ends of the leads ride lightly on the commutator. To the other ends of the leads connect a low reading voltmeter or a millivoltmeter. The brushes should previously have been set in a line on the commutator passing through the center of the main pole piece. At no load excite the machine to give normal voltage and move the brush-holder yoke until the voltmeter connected to the exploring brush reads zero. This is the proper position for the brush and will be the same for full load, if the shunt around the commutating field has been properly adjusted.

Fig. 12 shows a commutating-pole machine. Both motors and generators have the same arrangement of poles. Fig. 13 shows the electrical connection of a four-pole commutating-pole generator.

SYNCHRONOUS CONVERTERS

Comparison with D.C. Generator. In general appearance and construction the synchronous converter resembles the direct-current generator. The chief difference in appearance is that the synchronous converter has a set of collector rings mounted on, and insulated from, the shaft usually on the opposite end from the commutator. Another difference is seen in the relative dimensions of the magnetic circuit, which is much smaller in the synchronous converter than in a direct-current generator of the same capacity. The commutator end of a synchronous converter, or rotary converter, as it is often called, is exactly like any direct-current generator. At the other end the collector rings are tapped to equidistant points of the armature winding. As many taps are taken from the armature winding to each collector ring as there are pairs of poles.

Uses. The rotary is commonly used for converting alternating current into direct current. The voltage of the applied alternating current bears a fixed and definite ratio to the value of the direct-current voltage on the commutator. However, the machine may be run as an inverted rotary, having direct current applied to the commutator and delivering alternating current at the collecting rings.

Voltage Relations in Converters. *Two-Ring Rotary.* To understand the voltage relations in converters, consider briefly the case of a two-ring (single-phase) rotary. The maximum value of alternating-current voltage will occur when the commutator bars connected through the armature winding to the collector ring pass under the brushes. Assume E_{dc} the value of direct-current voltage. This is equal to the maximum value V of the alternating voltage. The effective value* V_e is equal to the maximum value V divided by $\sqrt{2}$; that is V_e equals $\frac{V}{\sqrt{2}}$; since V equals E_{dc} then V_e equals $E_{dc} \times 0.707$ or V_e. That is, taking the voltage on the direct-current end of a single phase rotary to be 100 volts, the a.c. voltage across the rings necessary to give this must be 70.7.

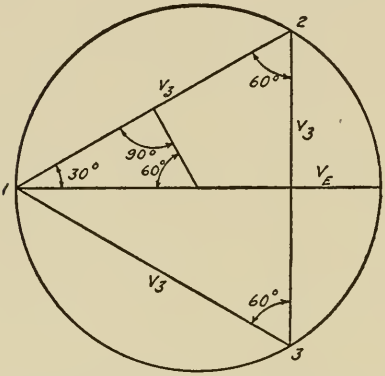


Fig. 14. Relation of A. C. Voltages in a Three-Ring Three-Phase Rotary Converter

Three-Ring Rotary. Let the effective value V_e for a single-phase rotary be represented by the diameter of a circle. Let Fig. 14 represent the relation of a.c. voltages in a three-ring three-phase rotary converter. *1*, *2*, and *3* represent the rotary rings where the impressed voltage is applied. V_3 represents the value of voltage between any two rings. The following is a simple proof of the value of V_3 in terms of V_e, and this in turn in terms of E_{dc}. Since we have already shown

$$V_e = \frac{E_{dc}}{\sqrt{2}}$$

$$\text{Cos } 30° = \frac{\frac{V_3}{2}}{\frac{V_e}{2}} = \frac{V_3}{V_e}$$

$$\text{Cos } 30° = \frac{1}{2}\sqrt{3} = \frac{V_3}{V_e}$$

---

* Alternating-current voltmeters read *effective* value of volts, not maximum value.

$$V_3 = \frac{\sqrt{3}}{2} \times V_e$$

But V_e was shown to equal $\frac{E_{dc}}{\sqrt{2}}$

$$\therefore \quad V_3 = \frac{\sqrt{3}}{2} \times \frac{E_{dc}}{\sqrt{2}} = .612\, E_{dc}$$

Which means that the alternating-current voltage across any two collector rings is equal to the direct-current voltage (measured across brushes of opposite polarity) multiplied by 0.612. Conversely, the direct-current voltage is equal to the alternating-current voltage across any two rings in a three-ring (three-phase) rotary converter divided by 0.612.

Four-Ring Rotary. Consider next the case of a four-ring (two-phase) rotary, and as in the previous case, let *1, 2, 3,* and *4* represent the rings. In Fig. 15

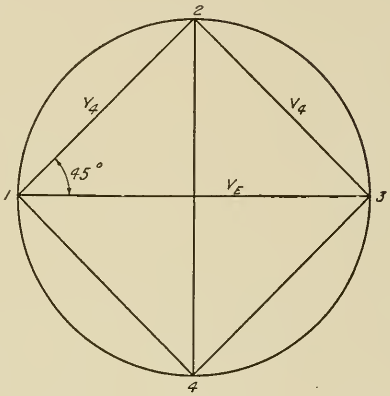


Fig. 15. Relation of A. C. Voltages in a Four-Ring, Two-Phase Rotary Converter

$$\text{Cos } 45^\circ = \frac{\frac{V_e}{2}}{V_4} = \frac{V_e}{2V_4}$$

$$\text{Cos } 45^\circ = \frac{1}{2}\sqrt{2} = \frac{V_e}{2V_4}$$

$$V_4 = \frac{V_e}{\sqrt{2}}$$

But
$$V_e = \frac{E_{dc}}{\sqrt{2}}$$

$$\therefore \quad V_4 = \frac{\frac{E_{dc}}{\sqrt{2}}}{\sqrt{2}} = .500\, E_{dc}$$

Consider then the voltages on a four-ring (two-phase) rotary in which *1, 2, 3,* and *4* are phases; the voltages between adjacent rings will be V_4 which equals $.500\,E_{dc}$, and the voltages across each phase will be the same as for a single-phase rotary, that is,

$$V_c = .707\,E_{dc}$$

Six-Phase Rotary. Fig. 16 represents a six-phase relationship of voltages. The collector rings are numbered *1, 2, 3, 4, 5, 6.* Consider the small triangle *1-2-a.*

$$\text{Sin } 30^\circ = \frac{\dfrac{V_e}{4}}{V_6}$$

$$\text{Sin } 30^\circ = \frac{1}{2}\sqrt{1} = \frac{V_e}{4V_6}$$

$$V_6 = \tfrac{1}{2}\,V_e$$

But $$V_e = \frac{E_{dc}}{\sqrt{2}}$$

$$\therefore \qquad V_6 = \frac{1}{2} \times \frac{E_{dc}}{\sqrt{2}} = .354\,E_{dc}$$

Note that Fig. 16 shows single-phase, three-phase, and six-phase relationships of voltages. V_6 is the voltage between any two adjacent rings represented by the sides of a hexagon inscribed in a circle whose diameter is equal to the effective voltage across the rings of a single-phase rotary. Measured in terms of the d. c. voltage, we have shown that V_6 equals $E_{dc} \times .354$.

In the dotted triangle *1-3-5* it will be noted the lines *1-3*, *3-5*, or *5-1* represent the voltage between collector rings, that is V_3. We have already shown that V_3 equals $E_{dc} \times .612$.

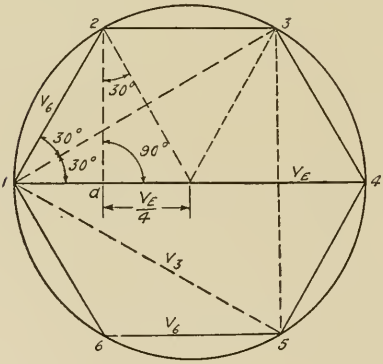


Fig. 16. Relation of A. C. Voltages in a Six-Phase Rotary Converter

A six-phase rotary has voltages impressed directly upon collector rings *1* and *4*, *2* and *5*, and *3* and *6*, which, from Fig. 16, will be seen to be equal to diameters of the circle. Therefore the same relation exists as for a single-phase rotary. Thus the alternating-current voltage across rings *1* and *4*, *2* and *5*, and *3* and *6* is equal to d. c. voltage multiplied by .707.

From the above explanation, and referring to Fig. 16, it will be seen that

a. c. volts across *1* and $2 = E_{dc} \times .354$
a. c. volts across *1* and $3 = E_{dc} \times .612$
a. c. volts across *1* and $4 = E_{dc} \times .707$

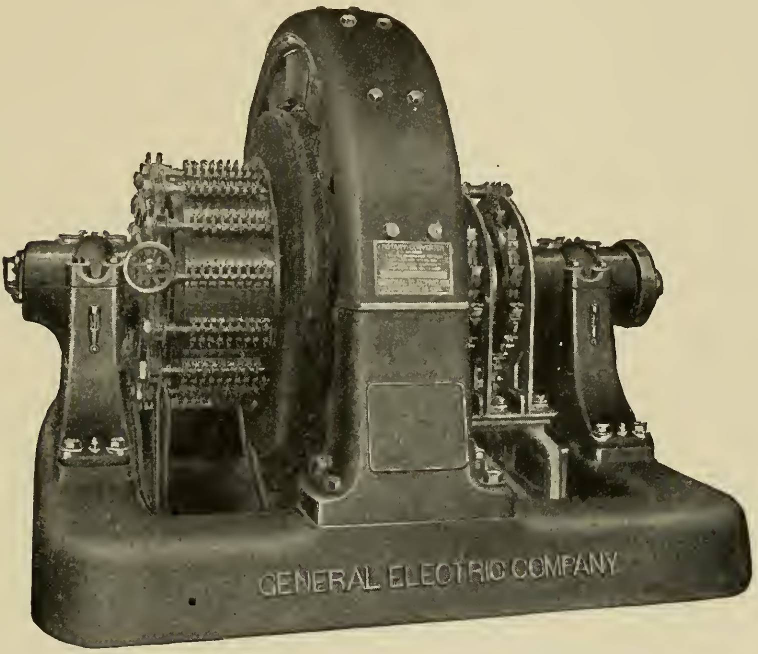


Fig. 17. General Electric 600-Volt Compound-Wound Rotary Converter

Conversely, $E_{dc} = V_6$ between rings *1* and $2 \div .354$
$E_{dc} = V_3$ between rings *1* and $3 \div .612$
$E_{dc} = V_c$ between rings *1* and $4 \div .707$

A modern type of railway rotary converter of the compound-wound type is shown in Fig. 17.

Switching of Synchronous Converters. The following instructions apply to the usual connections and to the switchboard equipment of General Electric compound-wound converters in railway service. Referring to Figs. 18 and 19, a machine should be started as follows, it being assumed that all switches are open before starting and that the potential plug is inserted in the potential receptacle on the direct-current switchboard panel, thus connecting the machine to the voltmeter. (See note.)

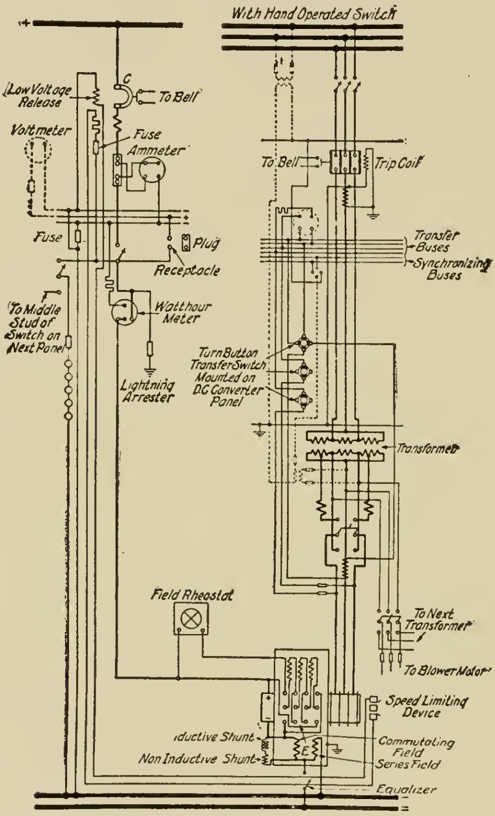


Fig. 18. Switching Diagram for Three-Phase Converters
Courtesy of General Electric Company

First: Close main high-tension switch *A*.

Second: Close starting switch *B* upward. (For six-phase machines with tandem switches, both switches *B* and *B B* should be closed upward.)

The machine will then run up to speed and lock in step, which will be indicated by a cessation of the beats of the direct-current voltmeter.

Third: Close equalizer switch *G*.

Fourth: Close field break-up and reversing switch *E* into the top position.

Fifth: For three-phase machines throw starting switch *B* quickly from top to bottom contacts, Fig. 18. With six-phase machine, Fig. 19, throw starting switch *B B* quickly from top to bottom contacts and then switch *B* from top to bottom contacts. Finally open switch *B B*.

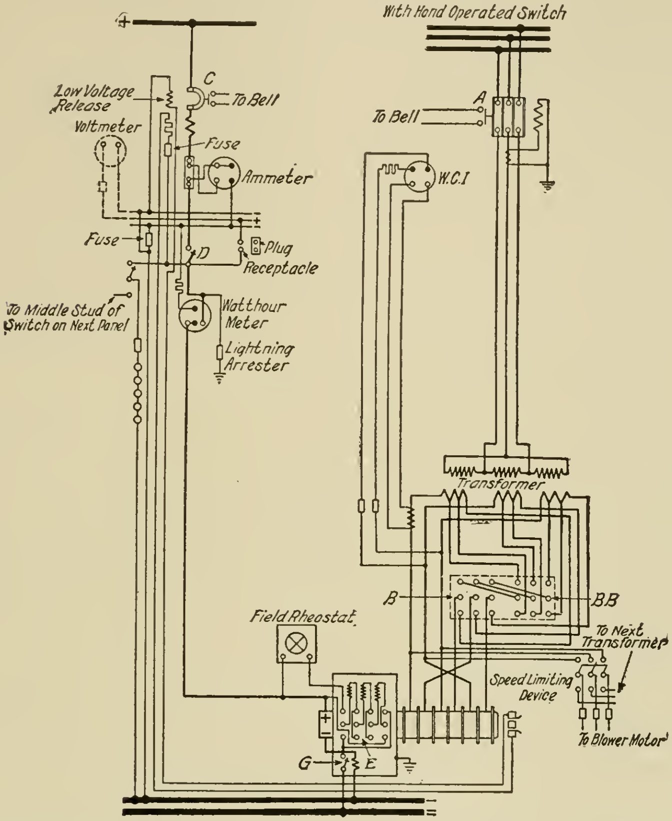


Fig. 19. Connections of Starting Switches for Six-Phase Converters
Courtesy of General Electric Company

NOTE: If other machine or machines are carrying load when a compound-wound converter is started, the correct polarity may be insured by closing the equalizer switch *G* when the machine locks in step. By watching the swings of the direct-current voltmeter as the machine approaches synchronism, switch *G* may be closed just previous to the last two or three swings, thus insuring proper locking on the first trial, if there is current for the series field from other machines. If the machine locks with the wrong polarity as indicated by the direct-current voltmeter needle going down off the scale, the field switch E must be closed first into the down position, which will cause the voltmeter to return above zero, when the switch E must be pulled out and closed into the top position. The reversal of polarity should be made while the machine is running on first starting tap.

Sixth: Adjust direct-current voltage to approximately that of the busbars.

Seventh: Push up the low voltage release of circuit breaker and close circuit breaker C.

Eighth: Close main switch D.

Ninth: Adjust the division of loads between machines, if more than one are in service, by means of field rheostats.

NOTE: Machines as now built do not have a shunt to the series field, so that the series field shunt switch exists only on older machines.

Shutting Down Synchronous Converter. To shut down a synchronous converter, open the circuit breaker C, pull out and turn the circuit-closing auxiliary switch to stop the ringing of the alarm bell; open the main switch D; open the high-tension alternating-current oil switch A; allow the machine to run down in speed until the voltage falls off to about one-fifth normal value before opening the field switch E or the starting switch B; open the field switch E, equalizer switch G, and starting switch B.

THREE-WIRE SYSTEM

Two Direct-Current Generators on Three-Wire System. In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the arrangements shown in Figs. 20 and 21 may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos, Fig. 20, to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This

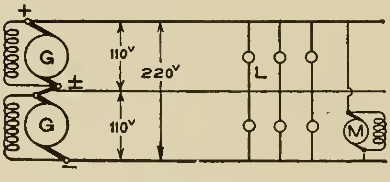


Fig. 20. Wiring Connections for Two D. C. Generators on Three-Wire System

can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

Generators with Balancer Set. Fig. 21 represents a 220-volt generator connected to the outside wires of a three-wire system. Two 110-volt machines are connected in series across the system, and the neutral conductor connects with the intermediate point between them. If the system is perfectly balanced, both 110-volt machines operate as motors without load. As the system becomes unbalanced, the machine on the heavier loaded side begins to operate as a generator and the other as a motor. The machines must be mechanically connected but can be separately regulated to give any desired voltage division between sides, and each machine can be compounded to compensate for unequal line losses and neutral drop when the system is unbalanced.

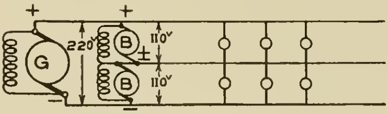


Fig. 21. Wiring Diagram for 220-Volt Generator with Balancer Set on Three-Wire System

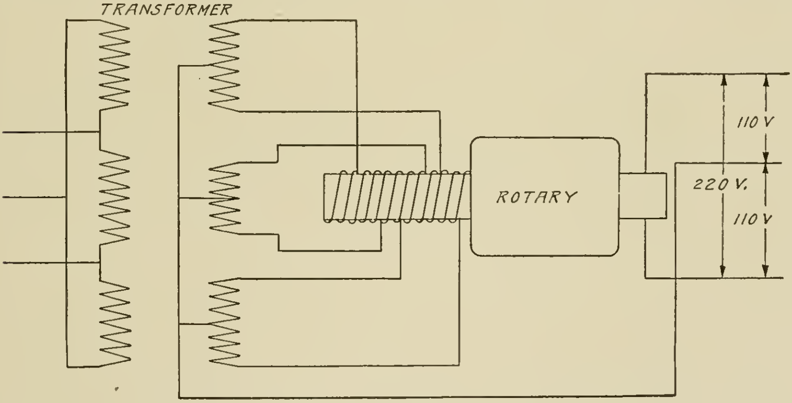


Fig. 22. Wiring Diagram for Three-Wire System with Rotary Converter Showing Transformer Connections

Three-Wire Systems from Rotary Converters. Where rotary converters are used to supply a three-wire system, the neutral conductor can be connected either to the middle points of the transformer secondaries, or to a compensator connected to the alternating-current leads.

The arrangement of the transformers or compensator windings must be such that they cannot operate reactively to prevent the current flow necessary to maintain the neutral, Fig. 22. Three-wire generators are often used for supplying three-wire systems. This machine is like a two-wire generator but has the armature winding tapped at suitable points. These taps are connected to a compensator or a balance coil from the middle point of which the neutral is obtained. Several forms of this type have been used by various manufacturers. One of these has the armature taps brought out to collector rings. The compensator is then mounted separately from the machine and connected through brushes to the rings.

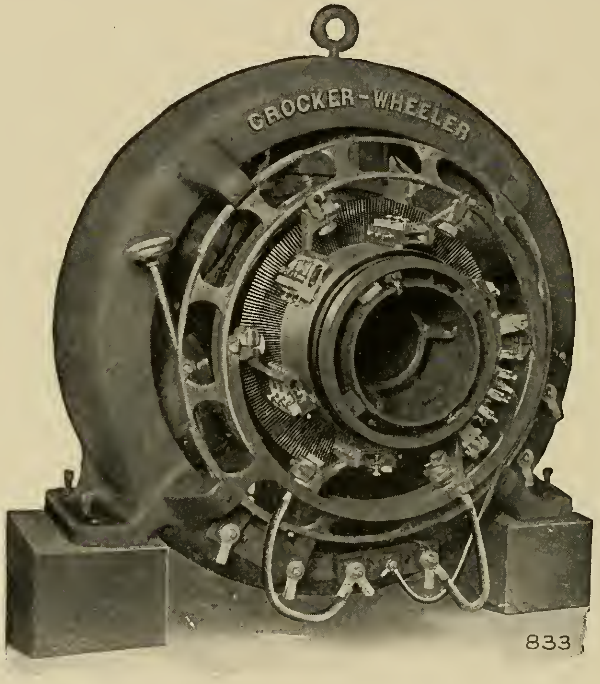
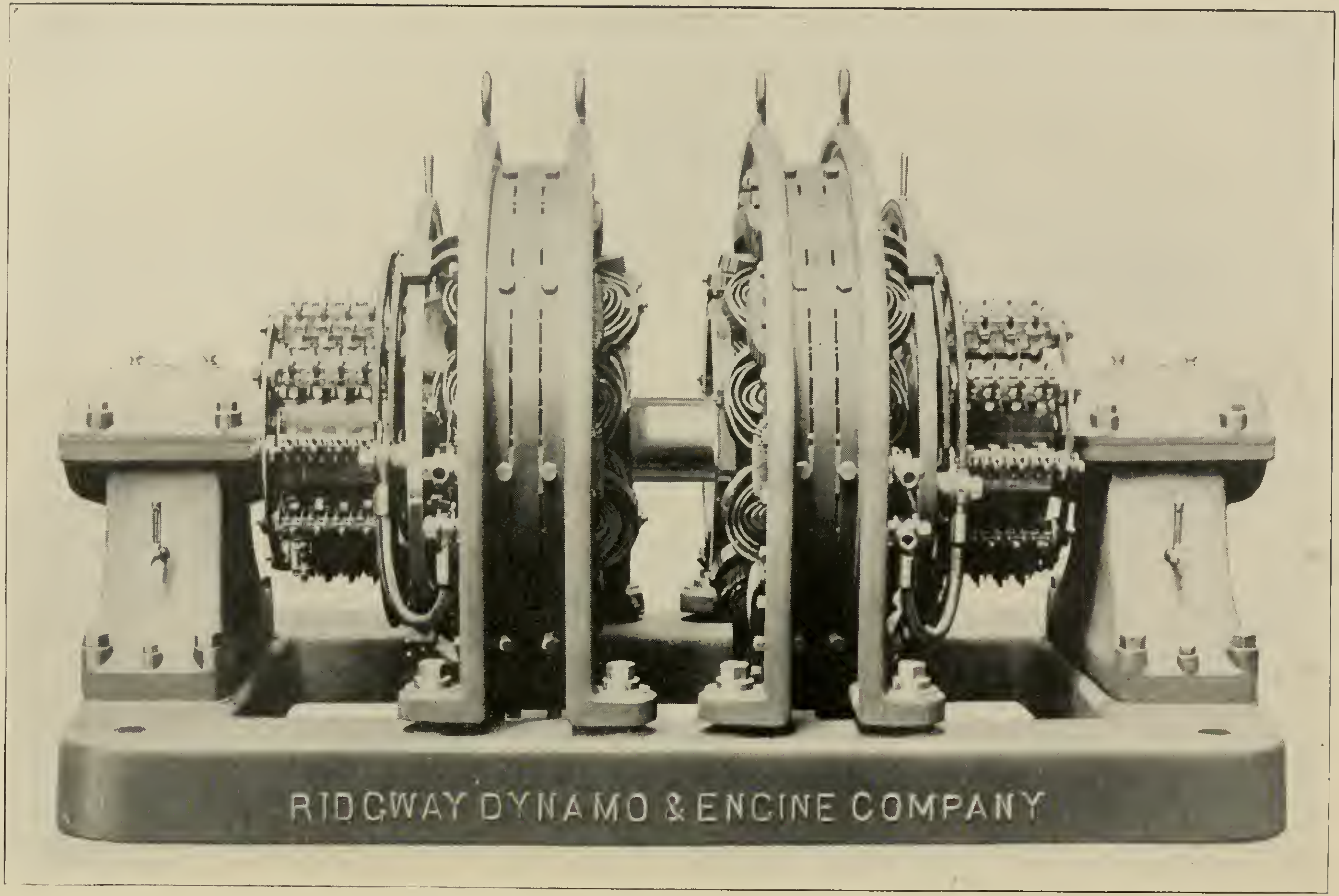


Fig. 23. Crocker-Wheeler 75 Kw. Three-Wire Generator

Since this form requires renewals and attendance on two or more sets of brushes and rings, some manufacturers have provided



125-KILOWATT SERIES GENERATOR DRIVEN BY A 275-VOLT DIRECT-CURRENT MOTOR

Courtesy of Ridgway Dynamo and Engine Company a winding in the armature to generate the voltage supplying the neutral conductor, which thus requires but one set of brushes and one collector ring, Fig. 23, in addition to the commutator brushes.

A later type of machine has a revolving compensator. This consists of a circular magnetic core upon which are mounted the coils. The core and coils are bolted directly to the back end of the armature spider. The single neutral connection is carried through the spider to a single collector ring mounted on the outer end of the commutator shell. This form has the advantages of few collector rings and brushes, small space, and greater simplicity in wiring.

DIRECT=CURRENT CONSTANT=POTENTIAL MOTORS

Shunt-Wound Motors. A motor to operate at nearly constant speed, with varying loads, on a d. c. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

Starting. In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get high efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or starting box containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch *Q*, to the motor and box, as indicated in Fig. 24. When the switch *Q* is closed, the arm *S* being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a a a* which prevent the rush of current referred to. The motor then starts and, as the speed rises, it generates a counter e. m. f., so that the arm *S* can be turned as shown until all the resistance coils *a a a* are cut out.

The arm *S* should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 24, the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm *S* is held in the position shown. If, however, the current applied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm *S* is released, being automatically moved back to the starting position by a spring.

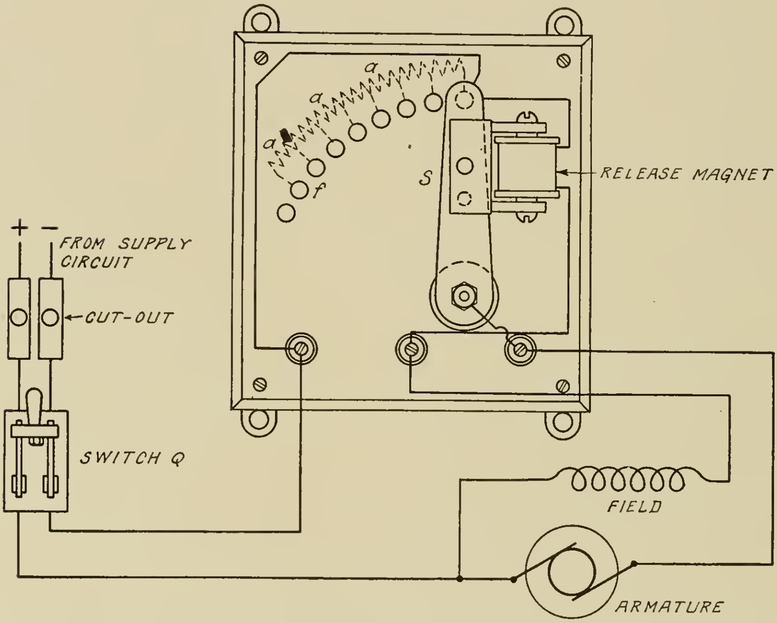


Fig. 24. Wiring Diagram for Connections of Shunt-Wound Motor to Starting Box

The coils *a a a* are made of comparatively fine wire which can carry the current only for a few seconds in a starting box; but if the wire is large enough to carry the full current continuously, it is called a "regulator", because the arm *S* may be left so that some of the resistances *a a a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying the e. m. f. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

Speed Control. The speed control of a shunt motor may be simply obtained as follows:

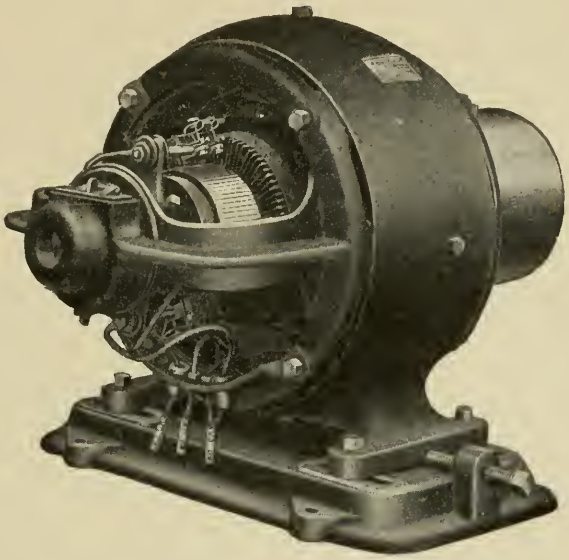


Fig. 25. Fort Wayne Northern Type B Shunt-Wound Motor

(a) For lower speeds, insert resistance in series with the armature circuit. The resulting internal resistance drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

(b) For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux and, to generate the same counter e. m. f., the motor must speed up.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and be damaged. A moderate decrease in field strength only is allowable; otherwise sparking becomes excessive. Fig. 25 shows a Fort Wayne Northern Type B shunt-wound motor.

Series-Wound Motors. The ordinary electric railway motor on the 600-volt system is the chief example of the class, Fig. 26. Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur, when the series type of motor is started, similar to that in the case just described; but it is less, because the field coils are in series, so that their resistance and self-induction reduce the excess. Furthermore, the counter e.m.f. is greater even at low speed because the heavy current produces a strong field.

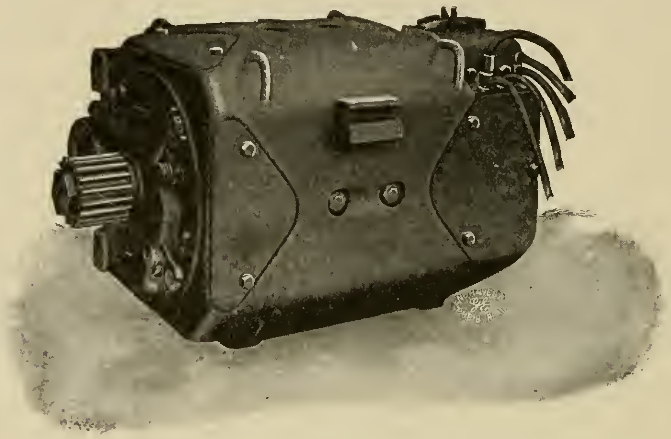


Fig. 26. Box Frame Railway Motor
Courtesy of General Electric Company

The connections, as indicated in Fig. 27, are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is, therefore, suited only to railway, pump, fan, or other work where variable speed is desired, and where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are: to secure a nearly constant speed with varying loads; to enable the motor to run at high efficiency when drawing small currents; and to prevent sparking at heavy loads.

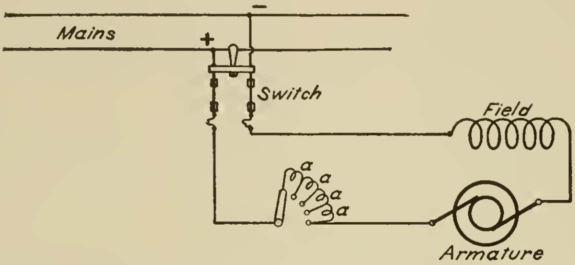


Fig. 27. Wiring Diagram for Series-Wound Motor Connections

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 28 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

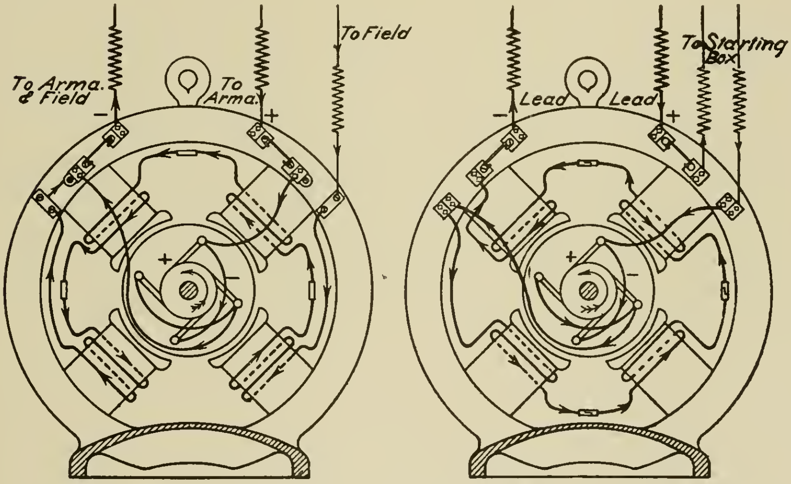


Fig. 28. Wiring Diagram for Four-Pole Shunt and Series-Wound Motors

Differentially-Wound Motors. This is a shunt-wound motor with the addition of a coil of large wire on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.

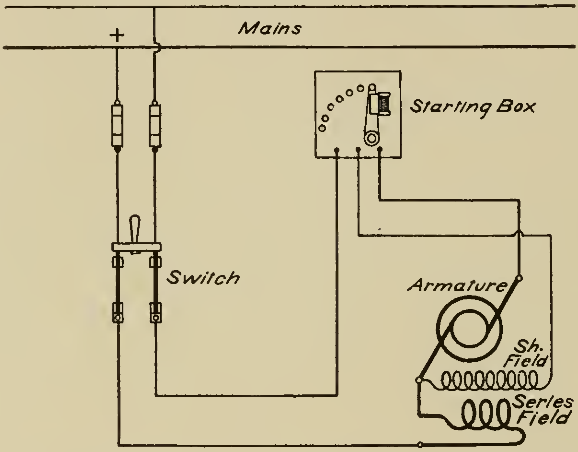


Fig. 29. Wiring Diagram for Compound-Wound Motor Connections

Compound-Wound Motors. This type of motor is also provided with both shunt- and series-field windings, Fig. 29, but in this instance they magnetize the field in the same direction, or, in other words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Method of Reversing Direction of Rotation in Motors. To reverse the direction of any direct-current motor, the direction of the current in either the field or the armature must be reversed. The direction of rotation would not be changed if the current in both the field and the armature were reversed. If the motor is compound or differentially wound and the direction of rotation is to be reversed, the current in the series winding must be kept so that it either assists or opposes, as the case may be, the current in the shunt field, whether the rotation is reversed by changing the current through the armature or the shunt field.

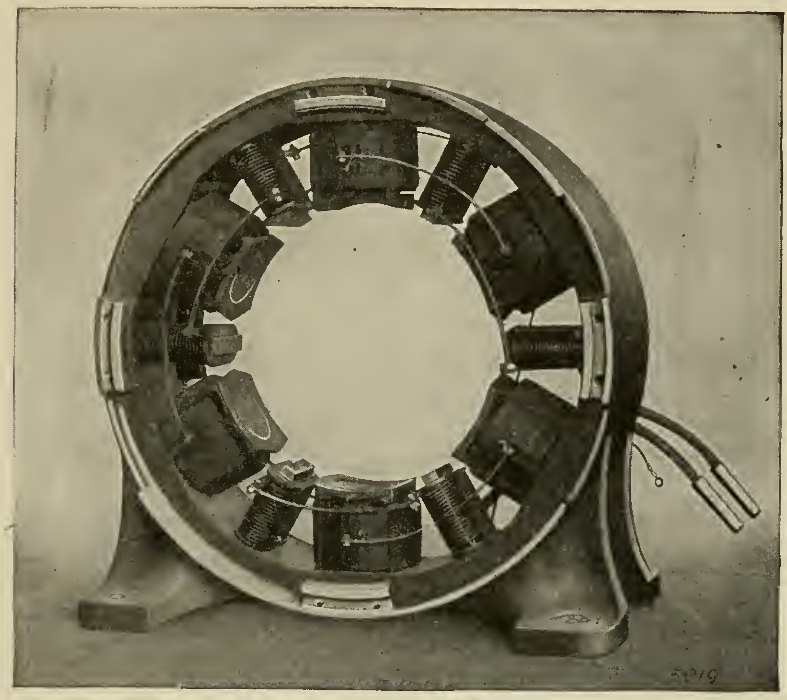


Fig. 30. Frame and Field Coils of Commutating-Pole Motor
Courtesy of Crocker-Wheeler Company

Commutating-Pole Motors. The general remarks as to mechanical and electrical points of difference between commutating-

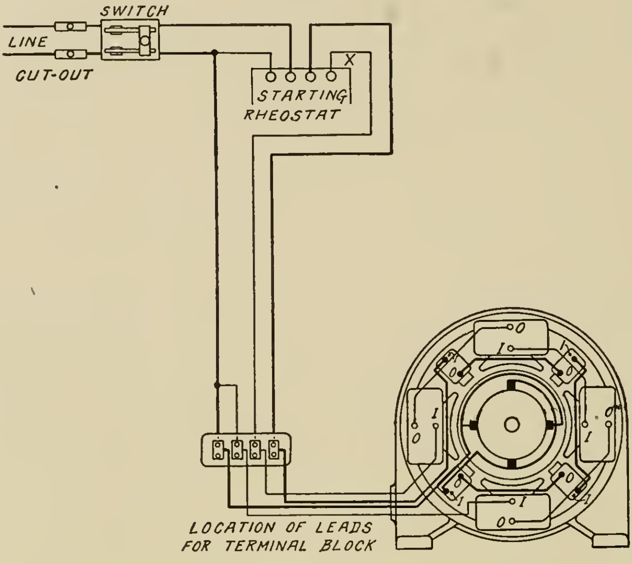

SWITCH
LINE
CUT-OUT
X
STARTING RHEOSTAT
LOCATION OF LEADS FOR TERMINAL BLOCK
MOTOR CONNECTED FOR COUNTER CLOCKWISE ROTATION

Fig. 31. Wiring Diagram of Rotation Connections for Commutating Four-Pole Shunt Motors

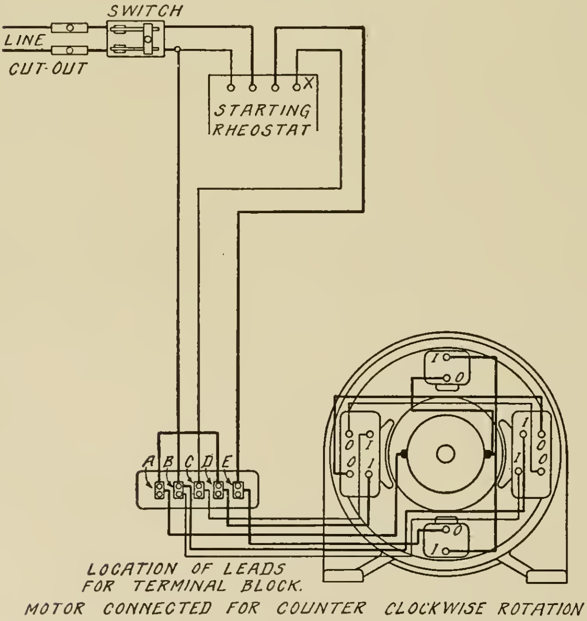

SWITCH
LINE
CUT-OUT
X
STARTING RHEOSTAT
A B C D E
LOCATION OF LEADS FOR TERMINAL BLOCK.
MOTOR CONNECTED FOR COUNTER CLOCKWISE ROTATION

Fig. 32. Wiring Diagram of Connections for Commutating-Pole Bipolar Compound Motors

and non-commutating-pole types of generators apply to similar types of motors.

The electrical neutral on commutating-pole motors is determined by shifting the brushes until the same speed is obtained in both directions with the same value of field current and the same voltage on the d. c. mains.

Fig. 30 represents the frame and field coils of a standard commutating-pole motor, and Figs. 31 and 32 show the method of wiring commutating-pole motors for both the four-pole shunt type and two-pole compound type.

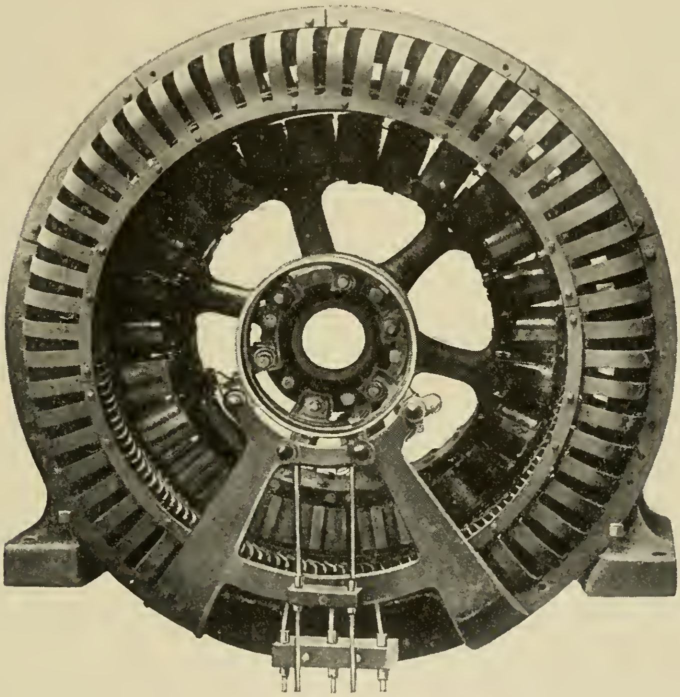


Fig. 33. Westinghouse Type E, 75 K. V. A. Generator, Showing Collector End

ALTERNATING-CURRENT GENERATORS

The present-day alternator consists of a stationary armature, called the stator, wound to generate either single or polyphase electromotive force, and a revolving field, called the rotor, excited from a separate 125- or 250-volt source. The exciting current is brought to the revolving field through collector rings mounted on and insulated from the shaft, the ends of the field winding being connected to these rings. Fig. 33 shows such a machine designed for direct connection to its prime mover. Machines of this class are quite often built with a small direct-current exciting generator mounted on the same shaft, as shown in Fig. 34. Small alternators sometimes have revolving armatures, the current, single or polyphase, being taken from collector rings connected to the armature windings.

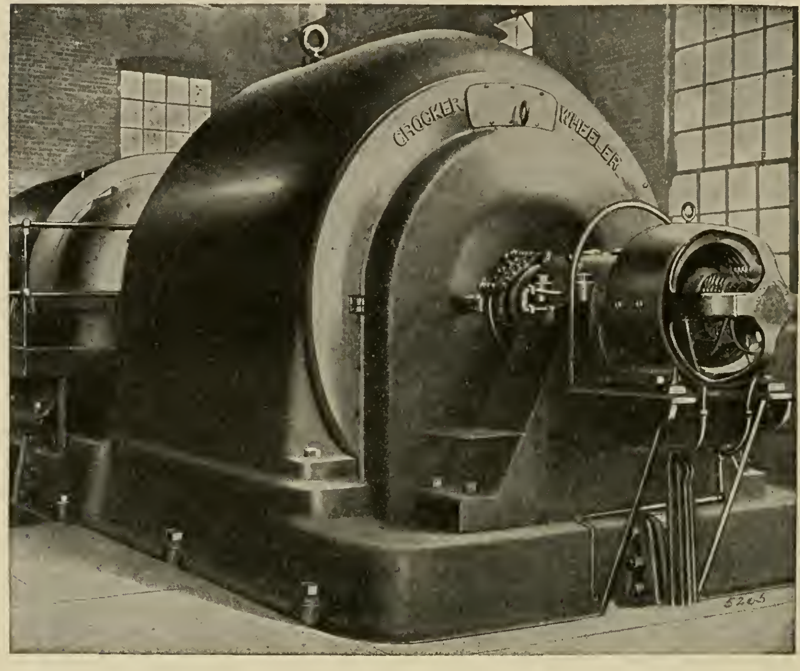


Fig. 34. Three-Phase Crocker-Wheeler Alternator, Showing Separate D.C. Exciter on the Same Shaft

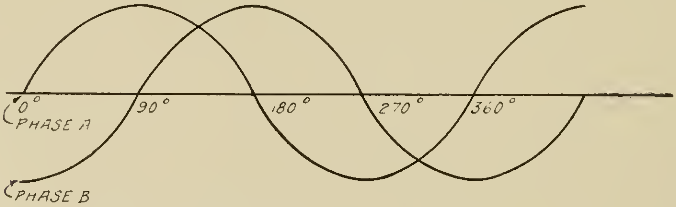


Fig. 35. Voltage Curves for Two-Phase Alternator

Single-Phase Type. There are a number of plants in this country still operating single-phase systems, but the advantages of using polyphase motors rather than single-phase motors in most power installations has caused this system to be practically abandoned. The single-phase generator need not be considered in discussing modern practice, since it is so little used.

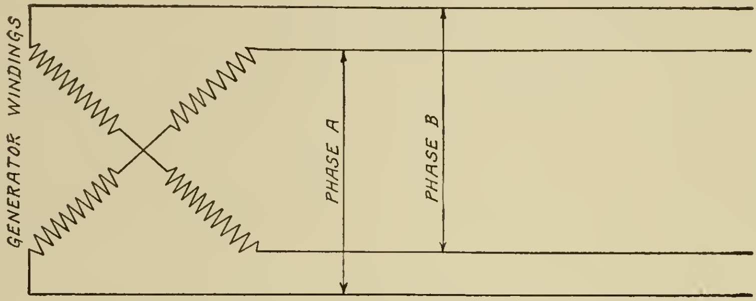


Fig. 36. Wiring Diagram for Two-Phase Four-Wire Generator with Armature Windings Ninety Degrees Apart

Two-Phase Type. A two-phase alternator has two armature windings arranged so that their voltages are 90 degrees out of phase. Fig. 35 shows the two voltage waves plotted in their relations, one being one-fourth of a cycle ahead of the other. Fig. 36 shows a two-phase four-wire generator with the armature windings represented 90 degrees apart. The voltages on phase *A* and phase *B* are equal.

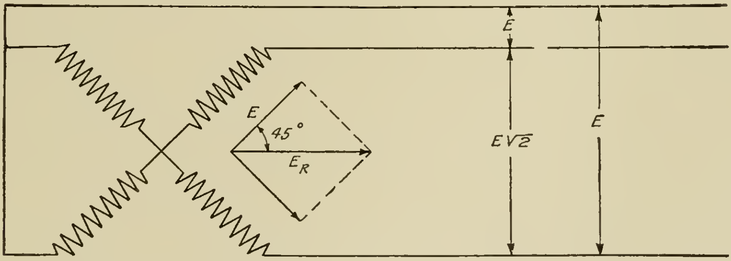


Fig. 37. Wiring Diagram for Two-Phase Generator Arranged for Three-Wire System

Two-phase generators are sometimes arranged with their two sets of armature windings connected together, as shown in Fig. 37. In this case only three wires are carried out to the distributing system. If the voltage of either phase is equal to *E*, then the voltage across the free ends of the inter-connected phase will be equal to $E \times \sqrt{2}$. (See Fig. 37.)

$$\text{Cos } 45° = \frac{\frac{1}{2}E_R}{E}$$

$$\text{Cos } 45° = \frac{1}{2}\sqrt{2}$$

$$\frac{1}{2}\sqrt{2} = \frac{\frac{1}{2}E_R}{E}$$

$$E_R = E \times \sqrt{2}$$

The current in any wire of a two-phase four-wire system is

$$I = \frac{KW}{2E}$$

in which KW is capacity of generator; E is voltage of phase A or B.

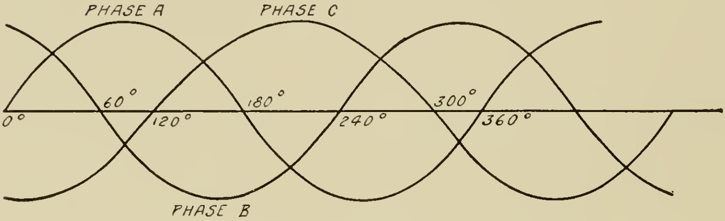


Fig. 38. Voltage Curves for Three-Phase Generator

Three-Phase Type. Three-phase generators have their armature windings divided into three sets of coils so arranged as to produce electromotive forces 120 degrees apart, Fig. 38. Armatures may be either Y- or Δ-connected, Figs. 39 and 40. In a Y-connected system, the line voltage is the phase voltage multiplied by $\sqrt{3}$ as shown, thus:

$$\text{Cos } 30° = \frac{\frac{1}{2}E_R}{E}$$

$$\text{Cos } 30° = \tfrac{1}{2}\sqrt{3}$$

$$\tfrac{1}{2}\sqrt{3} = \frac{E_R}{2E}$$

$$\therefore \qquad E_R = E\sqrt{3}$$

the line current is found to be the same as the current per phase. In a Δ-connected system, the line voltage is the same as the phase voltage, but the current per line is the $\sqrt{3}$ times the current per phase. In either system

$$W = EI\sqrt{3}$$

for noninductive circuit, in which W is watts output; E is pressure in volts, and I is current in amperes.

For an inductive circuit whose power factor is less than unity,

$$W = EI\sqrt{3}\cdot\cos\phi$$

in which $\cos\phi$ is power factor.

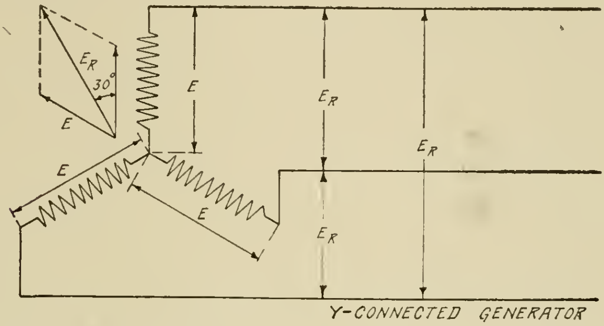


Fig. 39. Wiring Diagram for Y-Connected Three-Phase Generator

Alternators in Parallel. To run two alternators in parallel, several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called "synchronism."

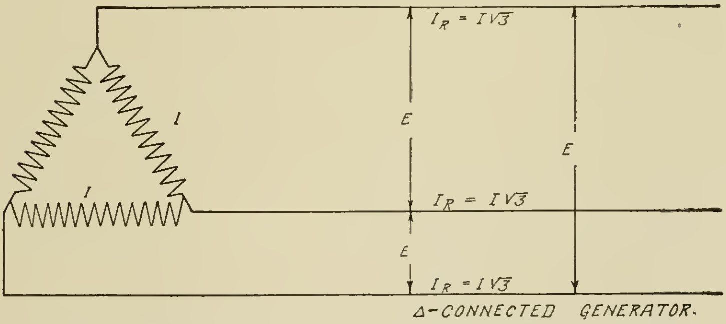


Fig. 40. Wiring Diagram for △-Connected Three-Phase Generator

Synchronizing Alternators by Lamp Indicator. It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 41, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch $A\,B$. Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When $A\,B$ is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assume machine M already in operation; bring up machine N to approximately the proper speed and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the

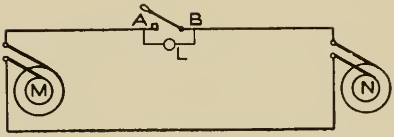


Fig. 41. Diagram of Two Single-Phase Alternators Arranged in Parallel

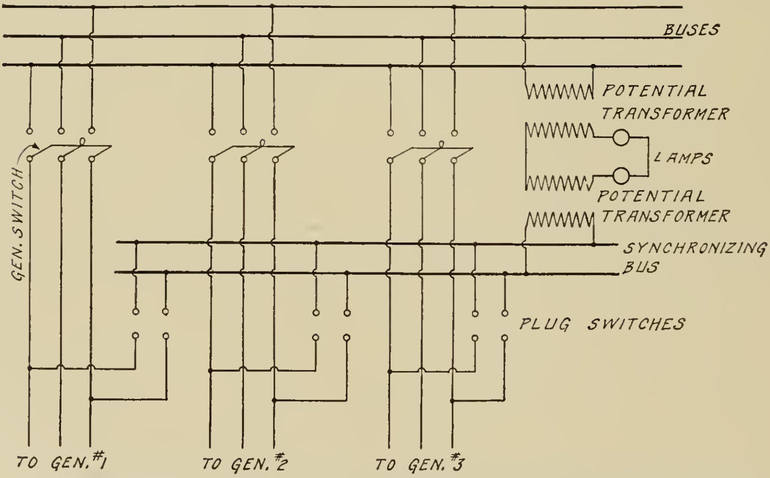


Fig. 42. Diagram of Connections for Synchronizing High-Voltage Alternators Through Step-Down Transformers

lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine *N* approaches synchronism, the slower the flickering. When it is very slow, and at the instant when the lamp is dark, throw the machine in parallel by closing the switch across *A B*. The machines are then in phase, and tend to remain so, since if one slows down, the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism rather than when they are receding from it; that is, at the instant the lamp becomes dark.

Fig. 42 shows the method of synchronizing high-voltage alternators through step-down transformers. When two three-phase alternators are first placed in operation, synchronizing connections should be made across each phase. If all the lamps become bright or dark simultaneously, the alternators are ready for parallel operation. After all phases have once been tested, it is only necessary to compare a corresponding phase from each machine to indicate synchronism.

The connections, as shown in Fig. 42, indicate synchronism when the lamps are dark. If it is desired that a condition of synchronism shall be indicated when the lights are at maximum brightness, reverse the secondary connection of either one of the potential transformers.

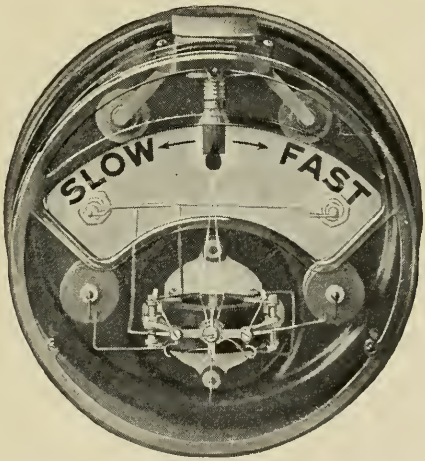


Fig. 43. Weston Synchroscope Showing Internal Construction

Synchronizing Alternators by Synchronizer. Synchronizing by means of lamps is not considered accurate enough in the modern station. There is manufactured an instrument called a "synchronizer," or "synchronism indicator," which gives much more accurate results. One form of this instrument, shown in Fig. 43, has a revolving pointer which indicates, *by its* *position,* the exact point of synchronism; *and by its direction of rotation,* whether the incoming machine is running too slow or too fast. Lamps are usually provided with this instrument as a check on its operation and for use in case of a failure of the instrument due to a burn-out or other cause. In the type shown, the lamp is back of the scale and lights up only when the machines are at or near synchronism.

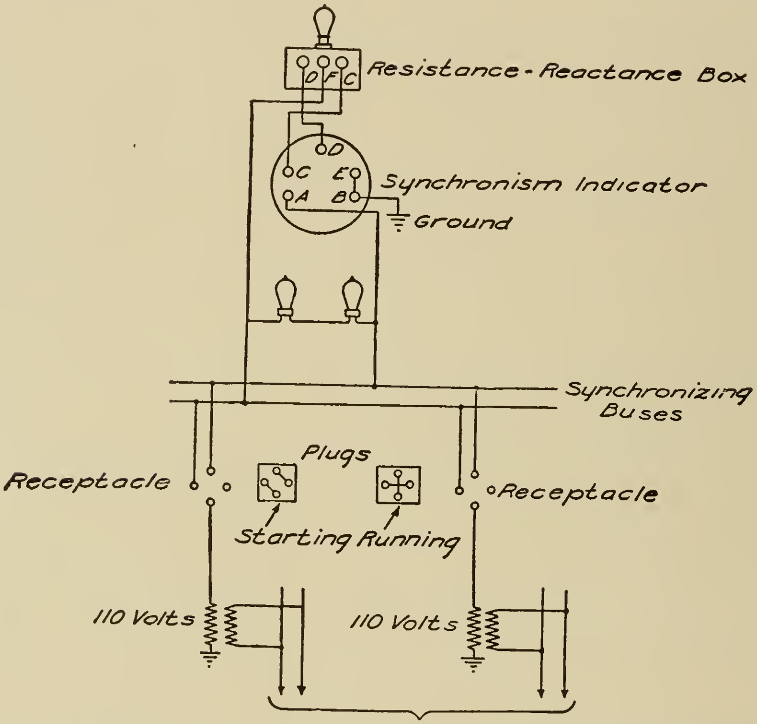
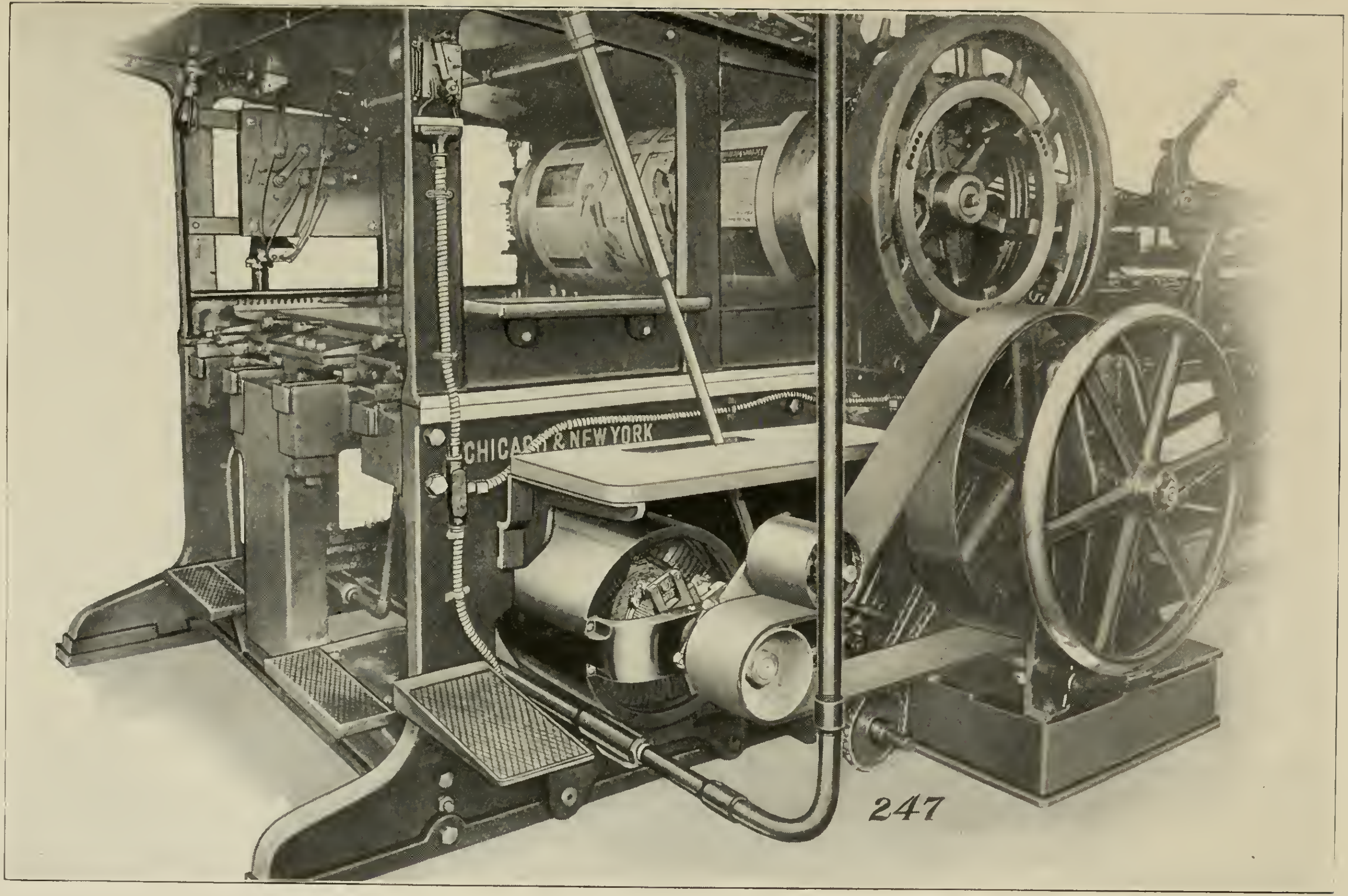


Fig. 44. Wiring Diagram for Synchronism Indicator with Potential Transformers, Secondaries Grounded. Synchronism Is Indicated When the Lamps Are Dark

Figs. 44 and 45 show two methods of connecting a synchronizer to two machines (one running and one starting) by means of plugs and receptacles mounted on the switchboard. Where the secondaries of the potential transformers can be grounded, which is usually the case, a common ground return can be used and the connections are much simplified.

When two alternating-current machines have been connected



MIEHLE PRINTING PRESS WITH STANDARD MOTOR DRIVE
Courtesy of Robbins and Myers Company

in parallel, the division of load should be adjusted. This cannot be accomplished as in direct-current machines by adjustment of the field rheostat. Change in field strength will cause more current to flow, but it will be 90 degrees out of phase with the potential and will not represent actual power. The only way to make the two machines supply proportional amounts of power is to adjust the input to their respective prime movers. The governor of the prime mover should be adjusted as if for an increase in speed to make the machine carry more load, and conversely to make the machine carry less load.

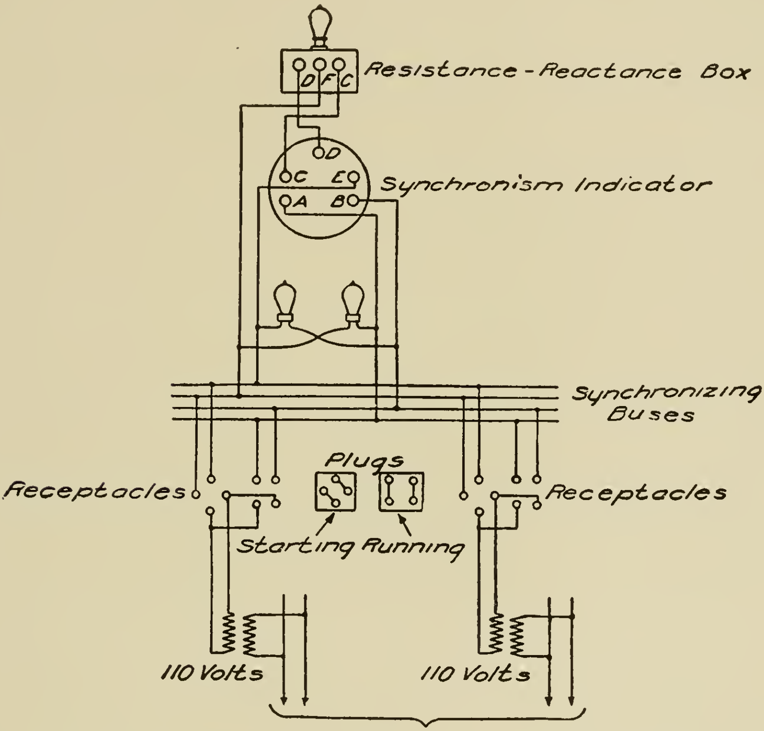


Fig. 45. Wiring Diagram for Synchronism Indicator with Potential Transformers, Secondaries Ungrounded. Synchronism Is Indicated When the Lamps Are Dark

If it is found necessary to increase the voltage of machines operating in parallel, the rheostats of all machines should be adjusted proportionally. If the rheostat of only one machine is shifted, cross currents will be caused to flow between machines, which do not represent actual power but do cause undesirable heating of the machines.

ALTERNATING-CURRENT MOTORS

Alternating-current motors may be generally classed as induction and synchronous types. The induction type of motor is particularly rugged in design, is simple of operation, requires little attention and a minimum of accessories; it does not tend to disturb the wave form of the system on which it is operating, and with normal load its power factor is fixed.

The synchronous motor closely resembles the revolving-field type of alternator and, in general, any standard type of alternator may be operated as a synchronous motor. This type of motor, therefore, requires practically the same number of accessories as an alternator. It requires care and skill on the part of the operator both in starting and in making the adjustments necessary for proper operation on the system. Since it is a synchronous piece of apparatus, like the generators supplying current to it, it may cause disturbance on the system on which it is operating unless very carefully handled. The power factor of this type of motor may be controlled by varying the excitation of its field. This feature allows the synchronous motor to be used for correcting the power factor of a system and causes its use in a large number of cases where the induction motor would otherwise be used because of its greater simplicity and ease of operation.

Induction Motors

Squirrel-Cage Type. The simplest form of polyphase induction motor is the ''squirrel-cage'' type, so-called because the rotating element with its windings short-circuited by a heavy copper end ring resembles a squirrel cage. Fig. 46 shows the rotor from a machine of this type. This rotor, also known as the secondary or armature, is made up of thin punched discs of specially treated iron. These punchings are provided with slots in which the windings are placed.

The stator, called also the field or primary, has windings distributed in the same manner as the winding in an alternator armature. The ends of the windings are brought out to a terminal board mounted on the frame of the motor, and the service lines are connected to the motor terminals. No connection is made to the rotor from any external source. Fig. 47 shows an exploded view of a motor of the type described.

The polyphase currents in the stator windings produce a revolving magnetic field. This in turn induces currents in the short-circuited winding on the rotor, which, on account of the reaction with the revolving magnetic field, causes the rotor to revolve. In order for any current to be induced in the windings of the rotor there must be a difference in speed between the revolving magnetic field and the rotor. It therefore follows that an induction-motor rotor never can revolve at exactly the same speed as the magnetic field of the stator; that is to say, it cannot attain synchronous speed. The difference between the speed of the rotor and the revolving magnetic field is called the "slip" of the motor. In motors of this class the slip varies from 2 to 6 per cent, depending on the size of the motor, large motors having the lower percentage of slip. Motors of the squirrel-cage type take a current equal to 3 to 4½ times normal full-load running current to produce full-load starting torque. The normal full-load efficiency of two- or three-phase motors of this type varies approximately from 87

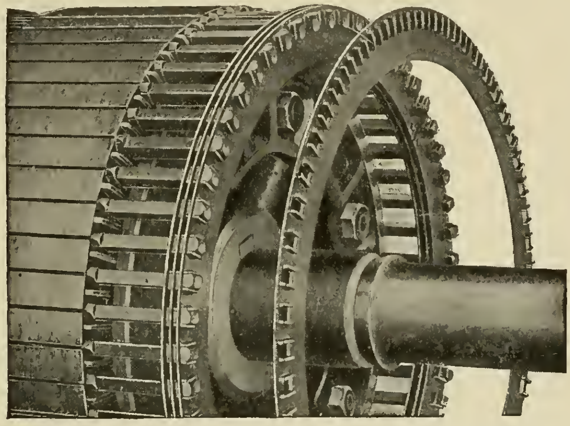


Fig. 46. Showing End Construction of Squirrel-Cage Rotor
Courtesy of General Electric Company

to 93 per cent, depending on the size of the motor. The power factor at full load varies from 85 to $90\frac{1}{2}$ per cent. Motors of this type operate at constant speed. Variable-speed a. c. motors will be considered later.

Reversing. To reverse the direction of rotation of induction motors, interchange leads as follows: For a two-phase four-wire motor, interchange the two leads of one phase; for a two-phase three-wire motor, interchange the two outside leads; for a three-phase motor, direction of rotation can be reversed by interchanging any two of the motor leads.

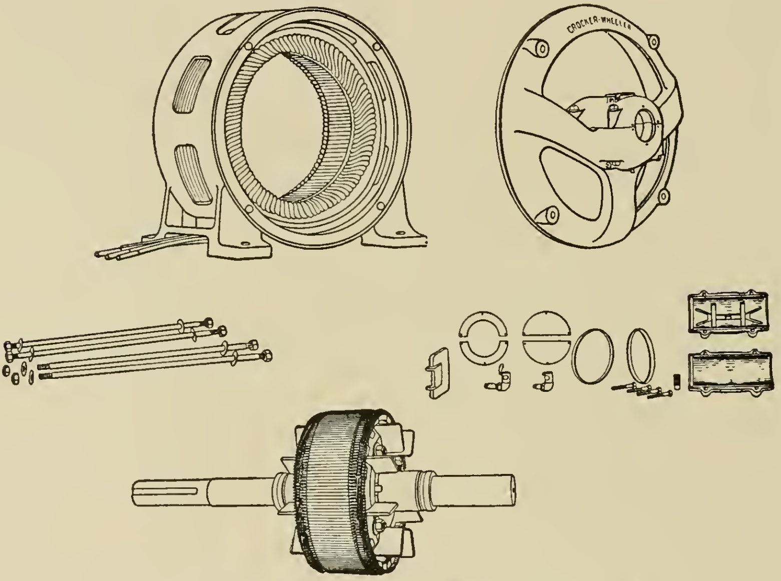


Fig. 47. Exploded View of Crocker-Wheeler Induction Motor

Output. The output of an induction motor varies with the square of the voltage at the motor terminals. If, for instance, the terminal voltage happens to be 15 per cent low (85 per cent of the rated voltage), a motor, which at the rated voltage gives a maximum of 200 per cent of its rated output, will give only $(85/100)^2 \times 200$, or 144 per cent of its rated output.

When an induction motor is overloaded, it draws an excessive current from the supply mains. The torque increases up to a certain value of slip. The rotor at this time has dropped back in position to such a point that the machine is unstable and, if the load is increased beyond this value, the machine comes to rest. This is called the "pull out" point of the motor. The speed of an induction motor varies directly with the frequency of the circuit on which it is operating.

Starting Compensator. It has already been pointed out that an induction motor of the squirrel-cage type can be started by simply closing the stator, or primary switch, but this calls for a very large rush of current. In order to cut down the starting current, when the maximum starting effort is not necessary, a starting compensator is usually employed. This compensator is an autotransformer, reducing the potential at the terminals of the motor and consequently diminishing the current taken by it.

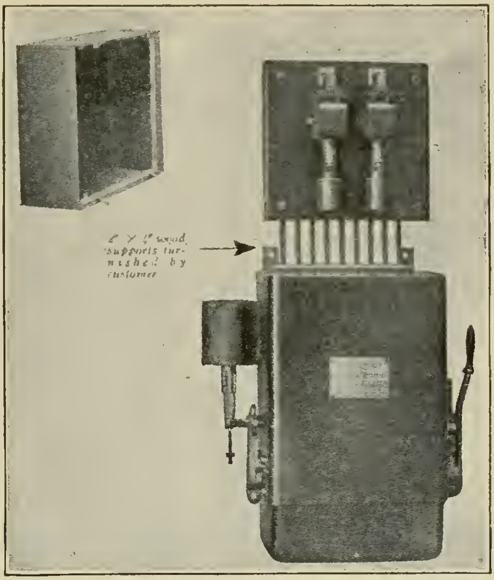


Fig. 48. Type NR General Electric Starting Compensator with No-Voltage and Overload Release with Enclosing Cover

Fig. 48 illustrates a compensator manufactured by the General Electric Company, and Figs. 49, 50, and 51 show the connections employed for two- and three-phase motors with compensators. Fig. 48 shows a compensator with overload relays mounted above it. These relays are arranged to trip the oil switch, when the current is excessive, and have time limit dashpots so that the switch will not trip during the starting operation. Fuses are sometimes used instead of these overload relays.

This type of compensator consists of coils (three for three-phase, two for two-phase) wound upon laminated iron cores, a spring return double-throw oil switch assembled in a metallic case, and a no-voltage release. To start the motor the switch should be thrown into the starting position with a quick firm thrust and held there until the motor comes up to speed (which usually requires but a few seconds) and then, with one quick firm movement, it should be pulled over into the running position, where it is held by a lever engaging with the no-voltage release mechanism.

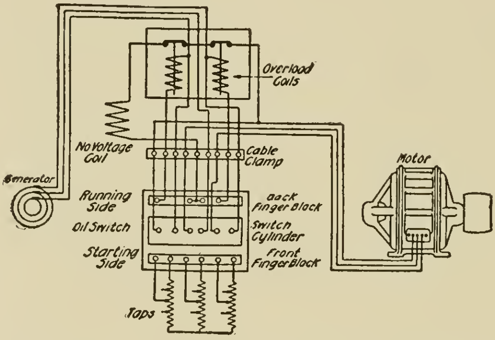


Fig. 49. Wiring Diagram for Three-Phase Starting-Compensator with Overload Release

Courtesy of General Electric Company

Never, in any case, should the motor be started by "touching," that is, by throwing the switch partly into the starting position and pulling it quickly out a number of times. This does not reduce the rush of current at starting, but, on the contrary, it produces a number of successive rushes in place of the one which it has attempted to avoid and, what is often a more serious matter, causes the contact fingers to be so badly burned that it is necessary to replace them.

When, however, the switch is properly thrown into the starting position, the current passes through the compensator. The windings of the compensator should be provided with a number of taps, so that the motor current may be obtained at a voltage considerably less than the line potential and thus start the motor with a minimum disturbance on the line.

With the switch in the running position, the compensator windings are entirely disconnected and the motor takes its current directly from the lines at full potential.

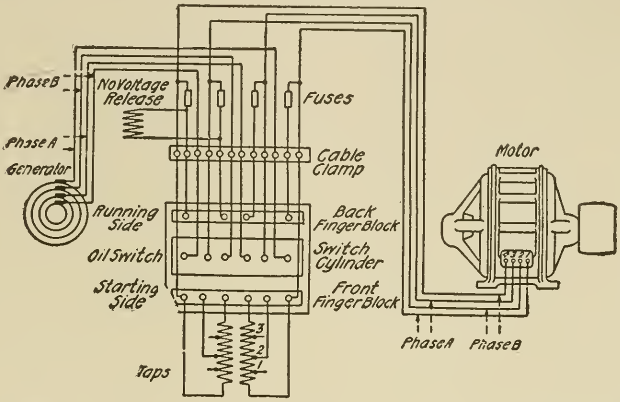


Fig. 50. Wiring Diagram for Two-Phase Starting Compensator for Four-Wire Circuit with Fuses

Courtesy of General Electric Company

Compensators are usually connected for low starting voltage and torque. If the motor will not start its load with these connections, the next higher voltage taps should be tried, and so on until taps are found which will give the required torque. Motors

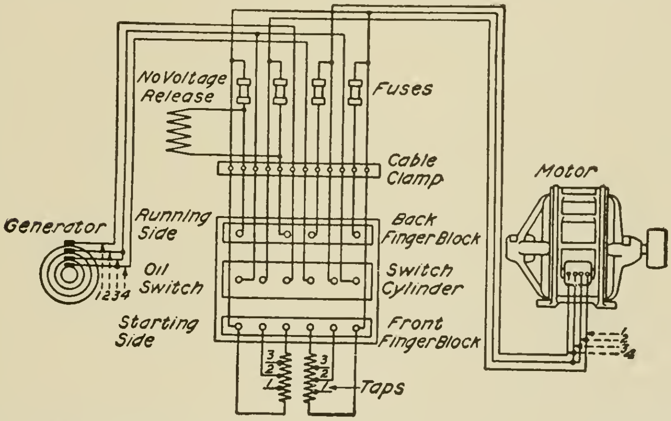


Fig. 51. Wiring Diagram for Two-Phase Starting Compensator for Three-Wire Circuit

Courtesy of General Electric Company

of small size (say, five h.p. or under) are usually started by connecting directly to the line without resistance or compensator.

Polar-Wound Type. Another form of constant-speed induction motor is one in which the rotor is definite or polar wound.

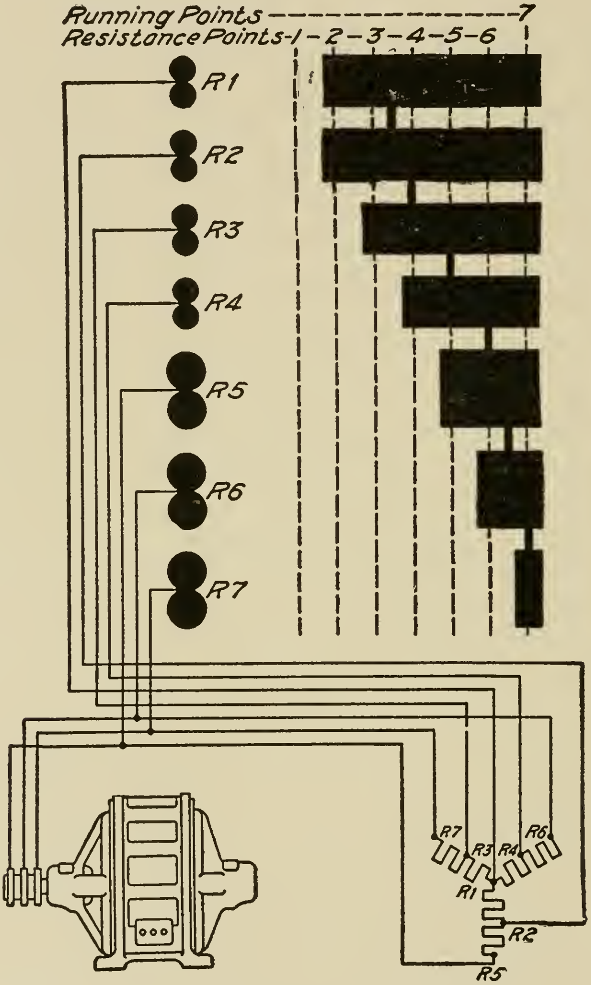
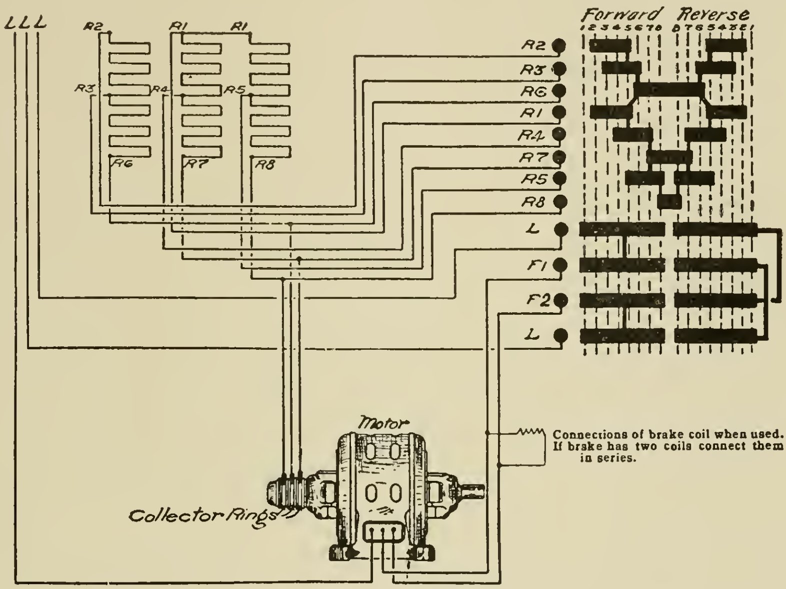


Fig. 52. Diagram of Simple Controller for Regulating the Resistance in the Rotor of a Slip-Ring Motor

The ends of this winding are connected to a resistance inside the rotor, arranged to be cut out while the machine is running, by a sliding contact, operated by a device on the motor shaft.

Starting. This type of motor is started without the use of a compensator in the leads to the stator to reduce the applied voltage. The device for cutting out the resistance is set so that all the resistance is connected in the rotor circuit when the motor is at rest. The stator, or primary circuit, is connected directly to the line and, as the motor attains speed, the successive steps of resistance are cut out until, on the last step, the resistance is short-circuited. The resistance must not be left in circuit after the motor has attained normal speed, since it is not intended for regulating the speed of the motor. This motor comes up to speed in about 15 to 18 seconds.



Connections of brake coil when used. If brake has two coils connect them in series.

Fig. 53. Control Diagram for Slip-Ring Induction Motor

Motors of this type exert a high starting torque. For instance, with a starting current $1\frac{1}{2}$ times full-load current, $1\frac{1}{2}$ times normal full-load torque is obtained. The power factor and efficiency of these motors are about the same as for the squirrel-cage type.

Slip-Ring Type. Still a third type of polyphase motor is one which has the polar-wound rotor similar to the one previously described. However, the ends of the Y-connected rotor windings are brought out to three collector rings mounted on and insulated from the shaft. Brushes bear on these rings and connect to some form of Y-connected resistance.

Control. In most sizes of motor a controller, similar to the ordinary street-car controller, cuts out the resistance in the rotor circuit step by step, the resistance being entirely short-circuited on the final step. The current to the stator or primary of the motor may also pass through the controller. Especially is this the case if the motor is to be operated in either direction. Figs. 52, 53, and 54 each show a method of control for the slip-ring type of induction motor.

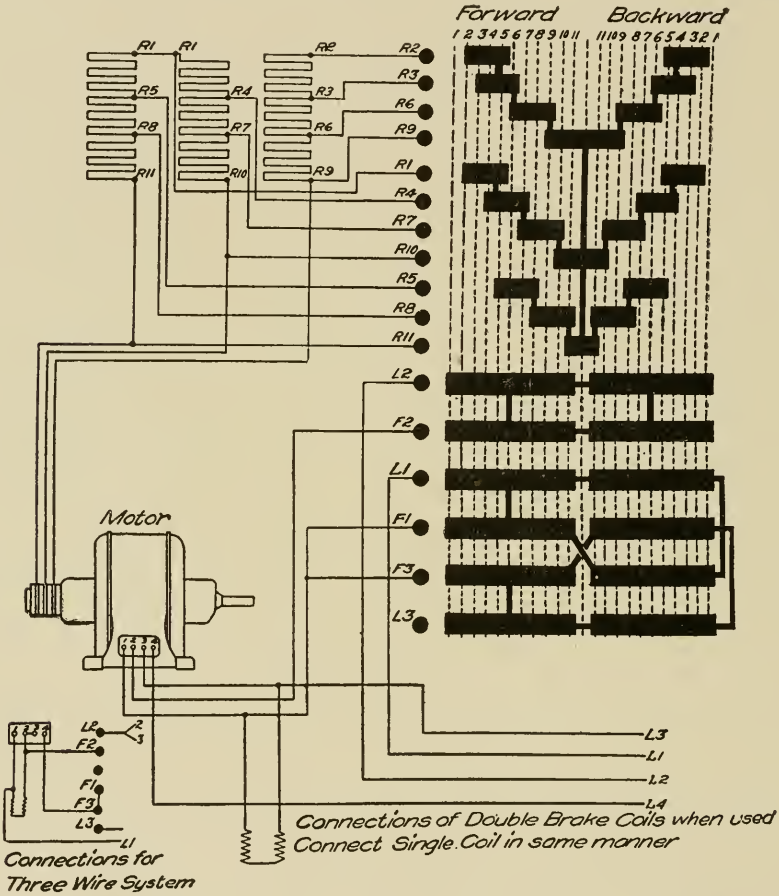


Fig. 54. Wiring Diagram for Control Mechanism of Slip-Ring Induction Motor

In larger sizes of motor, the control is accomplished by a system of electrically-operated contactors which give the same sequence of connections as the manual control already shown. This type of motor may be operated at constant speed after all resistance is cut out of circuit, or it may be used as a variable-speed motor, in which case the resistance must be proportioned for continuous duty on any point of the control. Examples of this kind are elevators, cranes, hoists, and other applications requiring variable speed.

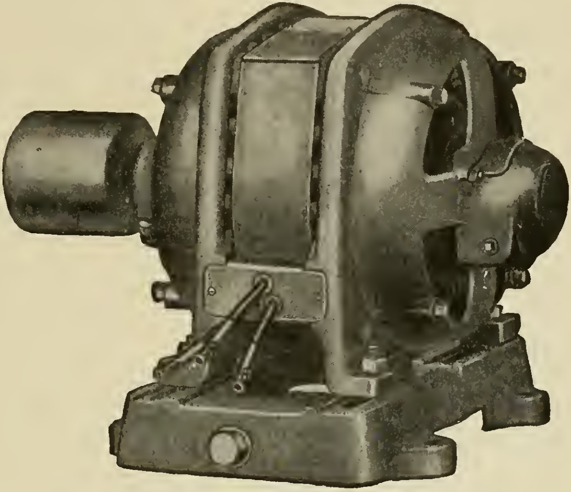


Fig. 55. Type KS Single-Phase Induction Motor
Courtesy of General Electric Company

Starting torque and current in this type of motor depend upon the resistance in the secondary circuit, full-load current giving approximately full-load torque.

Single-Phase Motors

Split-Phase Type. Owing to its simplicity, strength, and good electrical characteristics, the squirrel-cage polyphase motor is generally recognized as the ideal type for use on alternating-current power circuits. There are, however, many localities where for various reasons it becomes necessary for the central station to supply single-phase current to power consumers. The single-phase motor in sizes from about 1 to 15 h.p. takes care of such conditions.

Fig. 55 shows a General Electric single-phase motor, while Fig. 56 shows a Century Electric single-phase motor. This type of motor is suitable for constant-speed service where torque at starting does not exceed 140 per cent of full-load value.

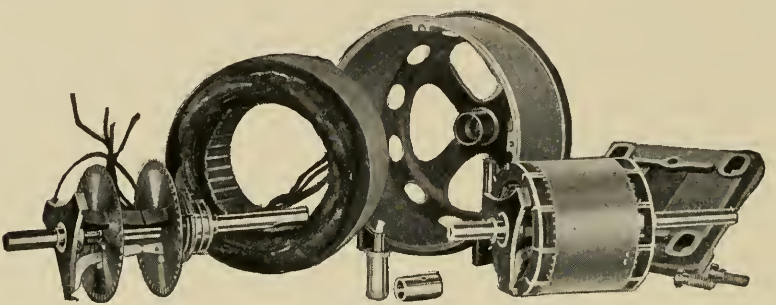


Fig. 56. Exploded View of Century Electric Split-Phase Induction Motor

Starting. In starting, the rotor revolves freely on the shaft until approximately 75 per cent of the normal speed is reached; the load is then picked up by the automatic action of a centrifugal clutch. The motor is started by means of a starting box containing resistance and reactance.

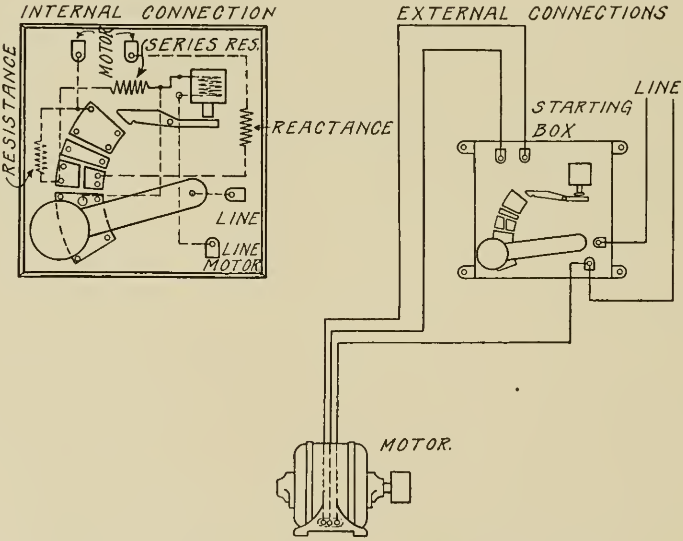


Fig. 57. Connections of Single-Phase Induction Motor with No-Voltage Release Starting Box

An induction motor designed to run on polyphase circuits will not start when its stator is connected directly to a single-phase circuit but, by providing the stator with a polyphase winding and ''splitting the phase'' of the applied single-phase current, sufficient starting torque is obtained. The current passing through the starting device will lag in the circuit having the reactance and cause the magnetic field to revolve. As soon as the motor has come up to speed, the connections to the stator are switched so that it is connected directly to the single-phase circuit. The motor will then continue to operate as a single-phase motor. Fig. 57 shows the connections necessary to operate the motor shown in Fig. 55. If a single-phase motor is started up by any external means and then thrown on the single-phase mains, it will continue to operate as a single-phase motor.

The efficiency of this type of motor at normal load varies from 70 per cent to 84 per cent, and the power factor from 67 per cent to 87 per cent in sizes of motors from 1 to 15 h.p.

Reversing. To reverse the direction of rotation, interchange any two of the three leads to the motor terminal block.

Repulsion Induction Motor. Another type of single-phase motor is that known as the ''repulsion induction motor''. The leading characteristics of the direct-current series-wound motor are well known. Operating through a wide range of speed and torque, this type has, however, no inherent speed regulation and its use is consequently confined either to fixed loads, like fans or pressure blowers, or to varying loads where the motor-controlling device is constantly under the operator's guidance. The speed, torque, and load characteristics of the series-commutator-type alternating-current motor being distinctly analogous to that of its direct-current prototype, the design fails to meet the requirements of constant-speed power service, this service demanding a motor which maintains good regulation after having once been brought up to speed, with torque values increasing as speed decreases; in other words, characteristics approaching those of the direct-current compound motor having the usual proportion of series-field winding.

The repulsion induction motor, however, gives this combination of series and shunt characteristics; that is, a limited speed and an increased torque with decrease in speed. In the straight repulsion motor, to secure the necessary starting torque, a direct-current armature is placed in a magnetic field excited by an alternating current and short-circuited through brushes set with a pre-determined angular relation to the stator. To further improve the operating characteristics of the plain repulsion motor, a second set of brushes (*i. e.*, the compensating brushes) is placed at 90 elec-

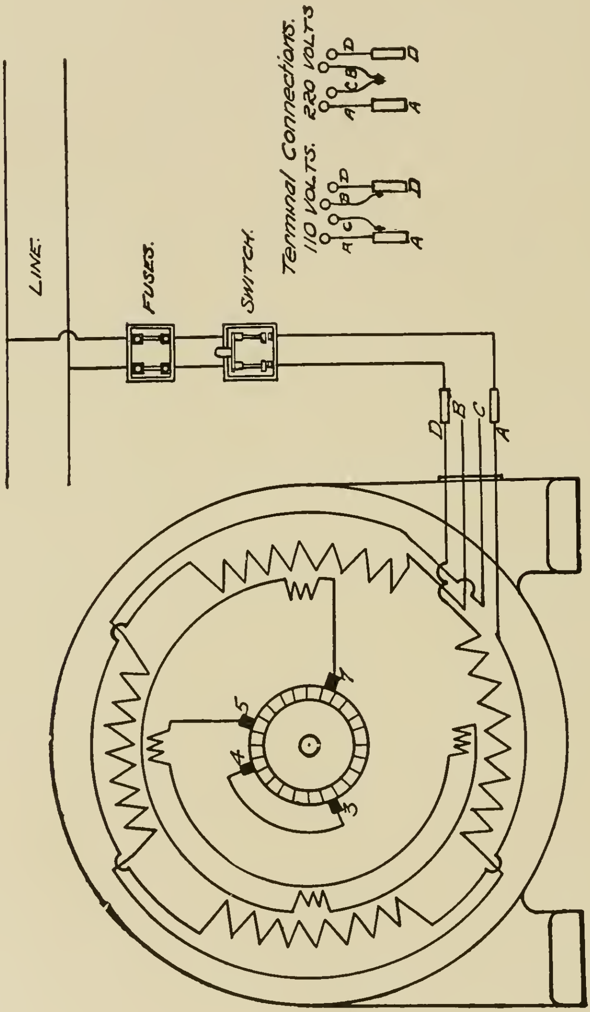


Fig. 58 Diagram of Connections for Constant-Speed Repulsion Motor. Brushes 3 and 4 Are Energy Brushes and Are Permanently Short Circuited. Brushes 5 and 7 Are Compensating Brushes

trical degrees from the main short-circuiting brushes (*i. e.,* the energy brushes), Fig. 58. The compensating field is auxiliary to the main field and impresses upon the armature an electromotive force in angular and time phase with the electromotive force gen-

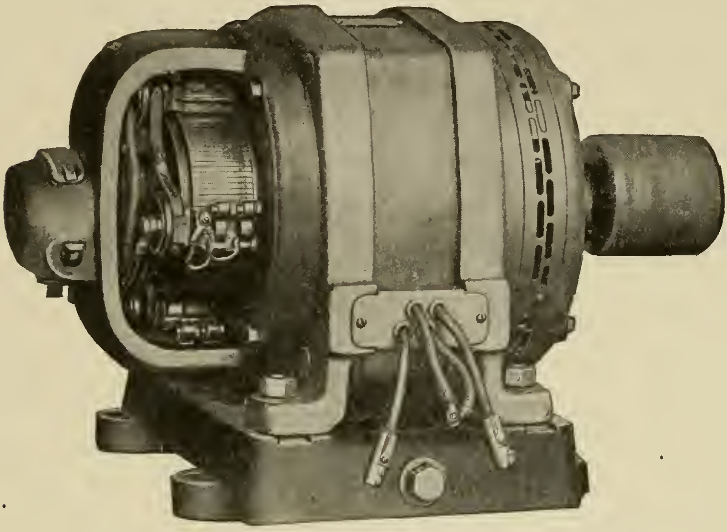


Fig. 59. Type RI Single-Phase Repulsion Induction Motor
Courtesy of General Electric Company

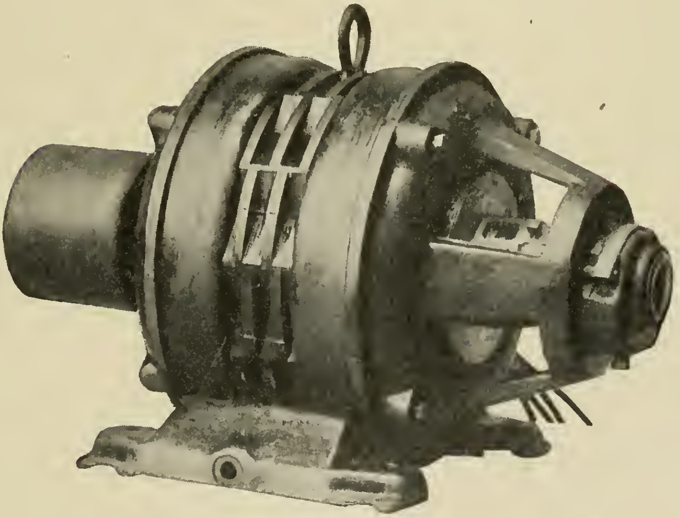


Fig. 60. Westinghouse Type AR Single-Phase Repulsion Motor

erated by the main field. In addition to correcting phase relation between the current and the voltage, thus giving approximately unity power factor at full load and power factors closely approaching unity over a wide range of load, the compensating field serves to restrict the maximum no-load speed and also permits, where varying speed service is involved, slight increase over synchronous values. The compensated repulsion motor is practically an induction motor capable of operation either above or below synchronous speed, possessing heavy starting torque and high power factor at all loads as well as excellent efficiency constants. The motor has no tendency to spark or flash over, since the armature coils, successively short-circuited by the energy brushes, are not inductively placed in the magnetic field and have consequently only to commutate a low generated voltage. Figs. 59 and 60 show standard types of repulsion induction motors.

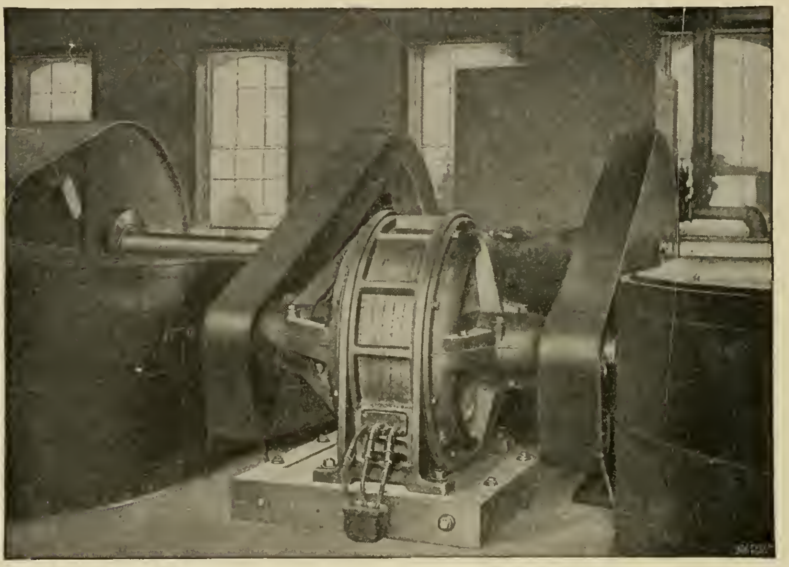
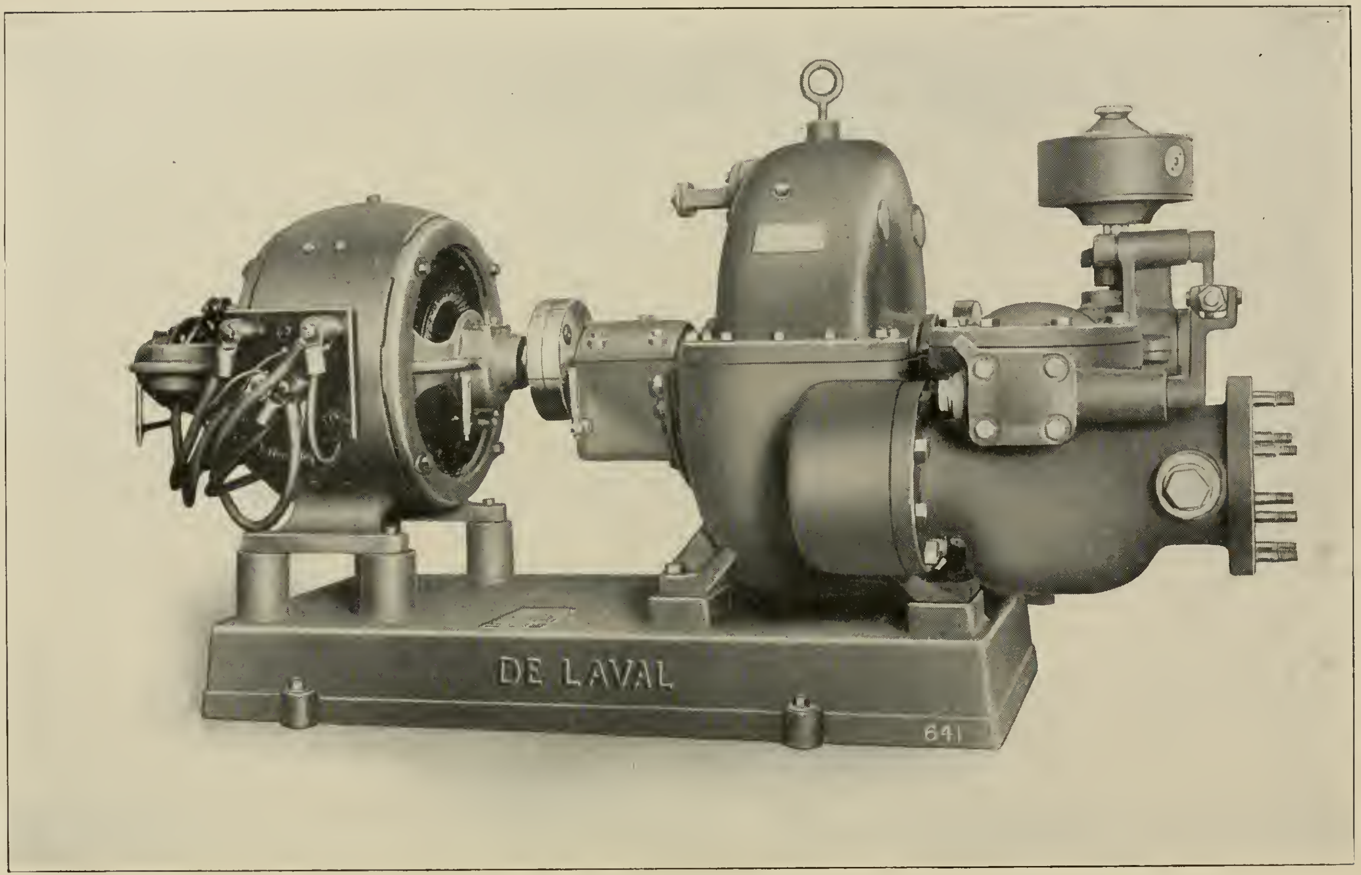


Fig. 61. Induction Motor Driving Two Beaters Through Silent Chain
Courtesy of General Electric Company

Starting Torque and Current. Starting torque is 200 or 250 per cent of rated-load torque with rated-line voltage. A starting current of 225 per cent of rated-load current is required to produce



DE LAVAL "CLASS C" TURBINE OF THE LOW PRESSURE TYPE DRIVING DIRECT-CURRENT GENERATOR
Courtesy of DeLaval Steam Turbine Company

rated-load torque. Where it is desired to reduce the starting current to the minimum, starting rheostats may be used.

The efficiency of the repulsion induction motor varies from 67 to 85 per cent and the power factor from 94 to 99 per cent, depending on the size of the motor.

The motor may be constant speed, constant speed reversible, variable speed, or variable speed reversible.

Typical Induction-Motor Installations. Induction motors of the three kinds described are extensively used in all manner of industrial plants, the type of motor depending upon its applicability to the work at hand. Figs. 61 and 62 show induction motors in different industrial applications.

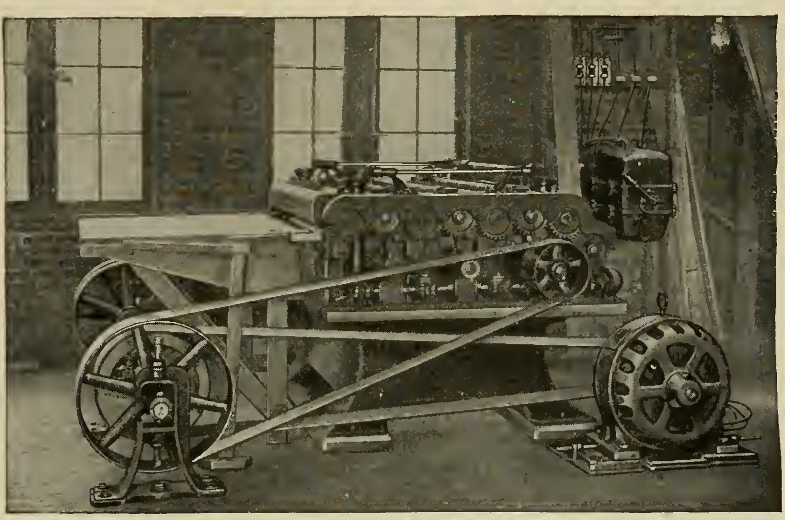


Fig. 62. Induction Motor Belted to Berlin Sander
Courtesy of Westinghouse Electric and Manufacturing Company

Synchronous Motors

As previously stated, the synchronous motor resembles the revolving-field generator, except that the field of the synchronous motor may be provided with a squirrel-cage winding. Fig. 63 shows a Westinghouse synchronous motor connected as a synchronous condenser.

Starting. This winding enables the synchronous motor to start up as an induction motor. Some device, such as a compensator, is used to reduce the line voltage, applied to the stator or primary of the motor, so as to reduce the rush of current in starting. Since the synchronous motor starts as a low-efficiency induction motor, it follows that it will not start under load, but will develop only enough torque to pull itself into synchronism.

The usual method of starting a synchronous motor is as follows: A starting compensator with several taps is provided, which may reduce the voltage applied to the stator of the motor to a value of from 50 to 70 per cent of normal line voltage, depending upon the amount of current required to bring the motor to about 95 per cent of synchronous speed. At this speed the field switch may be closed and the current in the field adjusted to about correct value. The full-line voltage may then be applied to the motor, when it will pull into synchronism. It will then be necessary to adjust the strength of the field to a value depending on

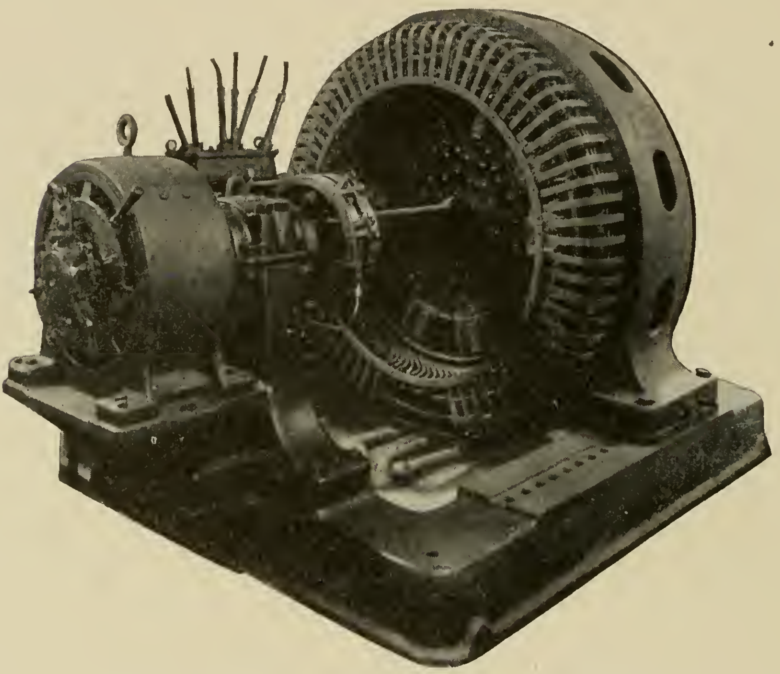


Fig. 63. 600 K.V.A. Self-Starting Synchronous Condenser
Courtesy of Westinghouse Electric and Manufacturing Company

whether the machine is to operate as a motor or as a synchronous condenser.

Some manufacturers recommend starting synchronous motors with the field short-circuited through a resistance. This is usually accomplished by making the discharge resistance heavy enough so that it will stand the induced current in the fields. In that case the field switch is left in the discharge clips during starting. The synchronous motor may be brought up to speed by an auxiliary starting motor and synchronized on the system, just as already described under the subject of a. c. generators.

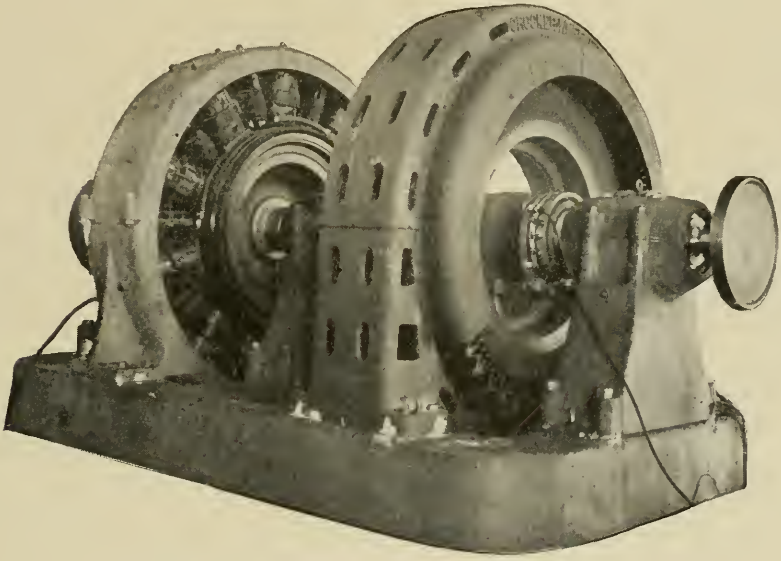


Fig. 64. 1200 Kw. Synchronous Motor-Generator Set
Courtesy of Crocker-Wheeler Company

Speed. The speed of a synchronous motor depends only on the frequency and is constant for a given frequency up to a certain point. If loaded beyond this point, the motor ''pulls out'', or comes to rest.

Uses of Synchronous Motors. *Driving Generators.* The most usual application of synchronous motors is for driving d. c. or a. c. generators. They are largely used for driving d. c. generators for railway, lighting, and power service because of their good speed characteristics. In such cases they are usually direct-connected to the generator and mounted on the same base with it, Fig. 64. In cases where it is necessary to obtain current at a frequency differing from the supply circuit, synchronous motors of one frequency are connected to a. c. generators of another frequency. Such combinations are called ''frequency changer sets''. Where the machines are direct-connected and therefore have the same speed, the ratio of poles on the two machines must correspond to the ratio of frequencies desired.

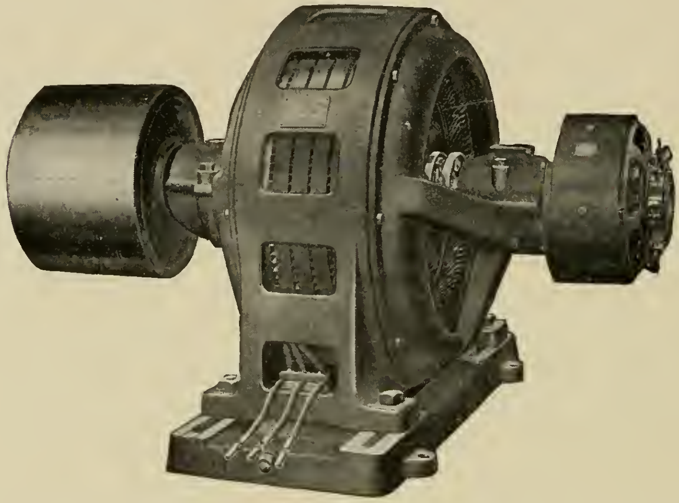


Fig. 65. General Electric Synchronous Condenser with Direct-Connected Exciter

Driving Compressors, Blowers, Etc. Synchronous motors are also well adapted for direct connection to some types of machines, such as air compressors and blowers. The speeds which can be obtained are well suited to such machines and considerable flywheel effect can be obtained, which is also of advantage.

Synchronous Condensers. Another very useful application of synchronous motors is their use as synchronous condensers. In any of the applications mentioned above, the field strength of the motor can be increased until the motor is taking leading current from the line. Thus instead of decreasing the general power factor of the system, as is the case with the induction motor, these motors may be made to increase the power factor of the system.

Where the motor is driving other load, this corrective effect must necessarily be but a small part of the total capacity of the machine. If the motor be floated on the line without carrying any mechanical load except its own rotor, a proportionally larger corrective effect can be obtained. A machine operated in this way is called a "synchronous condenser". In many installations having a large number of induction motors with a low average load, the power factor is very low. The increased capacity made available from the generators by increasing the power factor will often warrant a considerable investment in synchronous condensers in such cases. Fig. 65 shows a General Electric synchronous condenser with exciter which may be used under such conditions. The sole purpose of these machines is to raise the general power factor of the system.

OPERATION

Directions for Running Generators and Motors. *Preliminary Run with No Load.* If possible, a new machine should be run with no load or with a light one for several hours. It is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is apparently in perfect condition, because there may be some fault produced in setting it up, or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

Voltage and Current Regulation. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect and overcome any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused. Such directions should be thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and to give time for examination.

Keep Tools Away from Machines. Keep all tools or pieces of iron or steel away from the machine while running. Otherwise, they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces, thus ruining the machine.

Commutator and Brushes. Particular care should be given to the commutator and brushes, so that the former is kept perfectly smooth and the latter are in proper adjustment. Avoid lifting brushes when machine is operating, unless there are several in parallel.

Bearings. Touch the bearings occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Overloading. *Special care* should be observed by anyone who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. The matter of personal safety is of great importance in the installation, care, and management of dynamo-electric machinery, both from the humanitarian and from the financial standpoint.

Precautions in Handling the Circuit. The safest rule is never to touch any conductor carrying current, and never to allow the body to form part of an electric circuit, no matter what the voltage. This, of course, is a rule which cannot be followed strictly in practice. However, every precaution should be taken to prevent accidents, and every device which adds to the personal safety of the men should be employed. Rubber gloves, rubber shoes, or both, should be used in handling circuits of 500 volts or over. Also these articles should frequently be tested. Tools with insulated handles, or a dry stick of wood, should be used instead of the hand for handling the wires. It should always be remembered that a wire may be ''alive'' through some unknown change in connection or through accidental contact with another wire, even when it is thought to be ''dead''.

High Voltages. On the high a. c. voltages now so common, even the above precautions are not sufficient. No work can ever be done on such circuits unless they are entirely disconnected from all sources of power. In addition, the wires should be thoroughly grounded before being touched. In grounding, the ground connection should be first made and last disconnected.

Stopping Generators or Motors. *Operating Alone.* A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

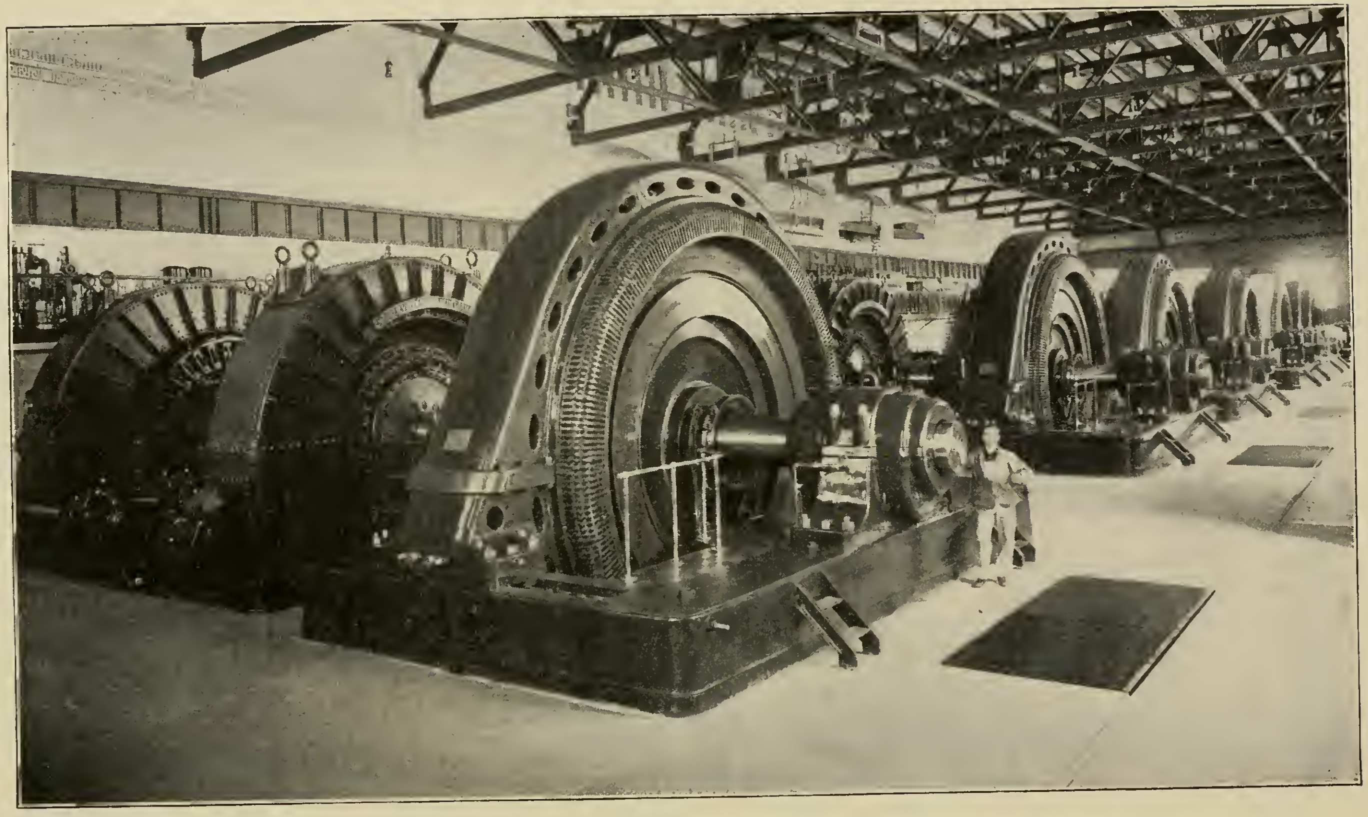
Operating in Parallel. However, when a generator is operating in parallel with other sources of power, it must not be stopped or reduced in speed until it is entirely disconnected from the system. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. For a d.c. machine this is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so as to cause a back current. For a.c. generators the load is reduced by adjusting the engine governor to reduce the input. Field rheostats should not be changed on a.c. generators.

Constant-Current Generator. A constant-current generator may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit,* and not to attempt to open it at any point, as this would produce a dangerous arc. Hence, a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded; the flash at the contact points, the discharge of magnetism, and the mechanical shock are all decidedly objectionable.

Constant-Potential Motor. A constant-potential motor is stopped by turning the starting-box handle back to the first position; or, *if there is a switch, or circuit breaker, in the circuit,* as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped it should be thoroughly cleaned and put in condition for the next run. When not in use, machines should be covered with some waterproof material.



INTERIOR OF GENERATING STATION OF THE ONTARIO POWER COMPANY, NIAGARA FALLS, ONT.

The generators are direct-connected to horizontal double turbines.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY

PART II

INSPECTION AND TESTING

MECHANICAL TESTS

Adjustment. Adjustment and the other points which depend merely upon mechanical construction are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by a thorough inspection. In fact, a very careful examination of all parts of a machine should always precede any test. This should be done for two reasons: *First,* to get the machine into proper condition for a fair test, and, *second,* to determine whether the materials and the workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wood or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. *Revolving Rotor by Hand.* The friction of the bearings and brushes can be tested roughly by revolving a small armature or rotor by hand, or slowly by power for a large one, and noting if it requires more than the normal amount of force. Excessive friction is easily distinguished, even by inexperienced persons. Another method is to revolve the armature and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed will continue to run for several minutes after the turning force is removed.

Revolving by Motor. Another method for measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, *first,* with brushes lifted, and, *second,* with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined, and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding about 2 per cent with the brushes up, or 3 per cent with the brushes down. The magnetic pull of the field of the armature may be very great, if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases but it should be corrected, if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then determining the friction. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at low speed, because at high speeds the effects of eddy currents and hysteresis enter and materially increase the apparent friction.

Balance. Perfection of balance of the revolving member of a machine is essential. On machines of small or medium size the revolving element should be laid on carefully leveled knife-edge steel ways. The heaviest side of the rotor will naturally assume the lowest position. Balance weights should then be placed diametrically opposite this point until the proper balance is obtained. It does not follow that the static balance will always be the correct running balance, and additional balancing may have to be done with the machine running at normal speed.

On very large machines, with which the preceding method can not conveniently be used, trial balance weights will have to be used until, by repeated tests, the proper position for the correct balance weights is obtained.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. *Resistance Method.* The most accurate way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating, for a specified time (usually 4 to 8 hours) under rated load. The rise of temperature is the percentage increase of initial resistance by the temperature coefficient for the initial temperature expressed in per cent. The standard room temperature or ambient temperature of reference was formerly 25 degrees centigrade but it is now fixed at 40 degrees centigrade, corresponding to high temperatures in engine rooms and in hot weather. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree centigrade rise in temperature, this being correct for 15 degrees centigrade, being .385 per cent at 25 degrees centigrade and .364 per cent at 40 degrees centigrade.

Thermometer Method. Thermometers are also largely used for determining the temperature rise in apparatus. The indications obtained by thermometer may be about 5 degrees centigrade lower than those obtained by the resistance method. When resistance is taken by thermometer, great care should be taken to prevent radiation. The thermometer should be covered with a pad of waste or cloth, not exceeding two inches in diameter, and allowance should always be made for the fact that the temperature is always less at the surface than at the interior.

The American Institute of Electrical Engineers has made general recommendations as to the limits of temperature advisable with various kinds of insulating material. Other authorities state the limits allowable for various types of machinery, for example, open and enclosed.

ELECTRICAL TESTS

WIRING

Before any work is done in connection with the installation of wires or cables, complete plans should be drawn, showing the proper relative location of all apparatus, the size of the conductors in every case, and the lengths of the runs. The path of the wires will depend on the system of wiring adopted but, in any case, it should be as simple and straightforward as possible. The rules of the National Board of Fire Underwriters should be closely adhered to, as well as the rules of any local board having jurisdiction. It is a good plan to have any doubtful points passed on by an inspector before the work is completed if the expense involved is very great. Otherwise, the work may have to be done over after completion, which more than doubles the expense. In general, the Underwriters recognize two methods of wiring—''exposed'' and ''concealed''.

Exposed Wiring. Exposed wiring on cleats and knobs or, for large cables, on cable racks with porcelain insulators is used less today than ever before. It has the great advantage of cheapness and accessibility, which will always make it popular in some places. However, the wires have an unsightly appearance and are subject to injury from sources external to themselves which greatly multiply the chances for trouble.

Concealed Wiring. The use of concrete construction in power plants of all kinds, and in industrial plants as well, has made it possible to make practically all wiring in such buildings concealed in iron, clay, or fiber conduits. Placing the conduits in the floors or walls puts the wires entirely out of sight, where they are not subject to injury from external sources, and where they are usually convenient for connection to the apparatus. Especially for power houses this method has become practically universal.

Houses, Office Buildings, Etc. The wiring of houses, office buildings, factories, etc., is practically all placed in conduits, as stated above. The voltage in all such cases is low; that is, usually not over 600 volts. The wires are insulated with rubber, paper, or varnished cambric of the thickness necessary for the voltage used, and are covered with braid if installed in dry locations. If moisture is likely to be encountered, the wires are covered with a lead sheath.

Power Houses. In power houses similar construction is used for voltages up to and including 13,200 volts. For busbars, especially when enclosed in fireproof compartments, bare bar or rod is usually used. For voltages above 13,200 there are many installations where the wires are insulated even up to 33,000 volts. However, insulation for such potentials is considered by most engineers as false protection. That is, it is not safe to depend upon the insulation to protect one against shock, and its presence is apt to give to the operator a false sense of security which might cost him his life. It has, therefore, become an almost universal practice to make all station wiring for high voltages of bare wire mounted on porcelain insulators. With such construction *it is evident* that one must never come near the wires, and the result is that the wiring is safer than if it were insulated.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct; otherwise the inductance would be excessive.

Size of Conductors. All conductors, including those connecting the machine with the switchboard, as well as the busbars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The voltage drop between the generator and the switchboard should not exceed one-half per cent at full load. Excessive drop at this point interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe-carrying capacities of copper conductors as recommended by the National Board of Fire Underwriters are given in Table II.

TABLE II

Safe-Carrying Capacities of Copper Wires

Rubber Insulation		Other Insulations	
B. & S. G.	Amperes	Amperes	Circular Mils
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The safe-carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

PROTECTIVE APPARATUS

Switches. Switches are devices for closing or opening a circuit. Several different kinds are used, the design depending upon the character and the severity of the service. For low voltage circuits (125 or 250 volts) of 10 amperes or less, snap switches are often used. These switches are usually of the kind mounted on porcelain bases and enclosed with a metal cover. The handle operates on a spring which in turn operates the contact blade or blades. Thus the contacts remain in position until the spring pressure overcomes the friction, when the switch opens or closes with a quick snapping action.

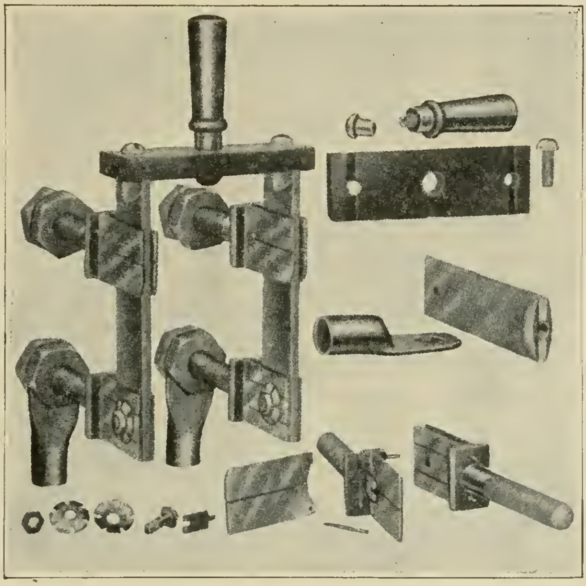


Fig. 66. Exploded View of Double-Pole Lever Switch
Courtesy of General Electric Company

Lever Switches. Lever or knife switches consist of blades of copper operating in clips attached to copper blocks. One end of the blade is hinged in the clips and spring washers are provided to insure pressure enough for good contact and to take up any wear between blade and clips. An insulating handle is attached to the other end of the blade. If the switch has two or more poles, they are fastened together by means of an insulating crossbar, and the handle is attached to the crossbar instead of to the blade direct. Fig. 66 shows such a lever switch for mounting on a switchboard. It also shows an exploded view of the parts.

The general construction, spacing, etc., is, in this country, fixed by the rules of the National Board of Fire Underwriters.

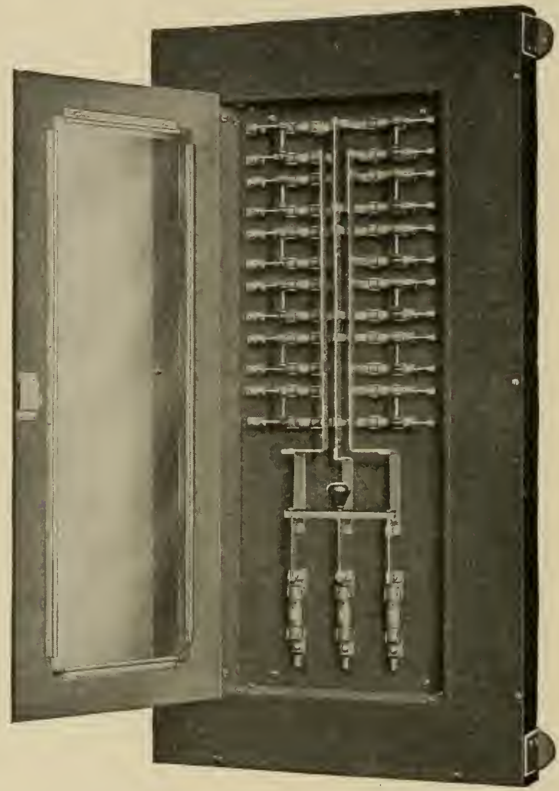
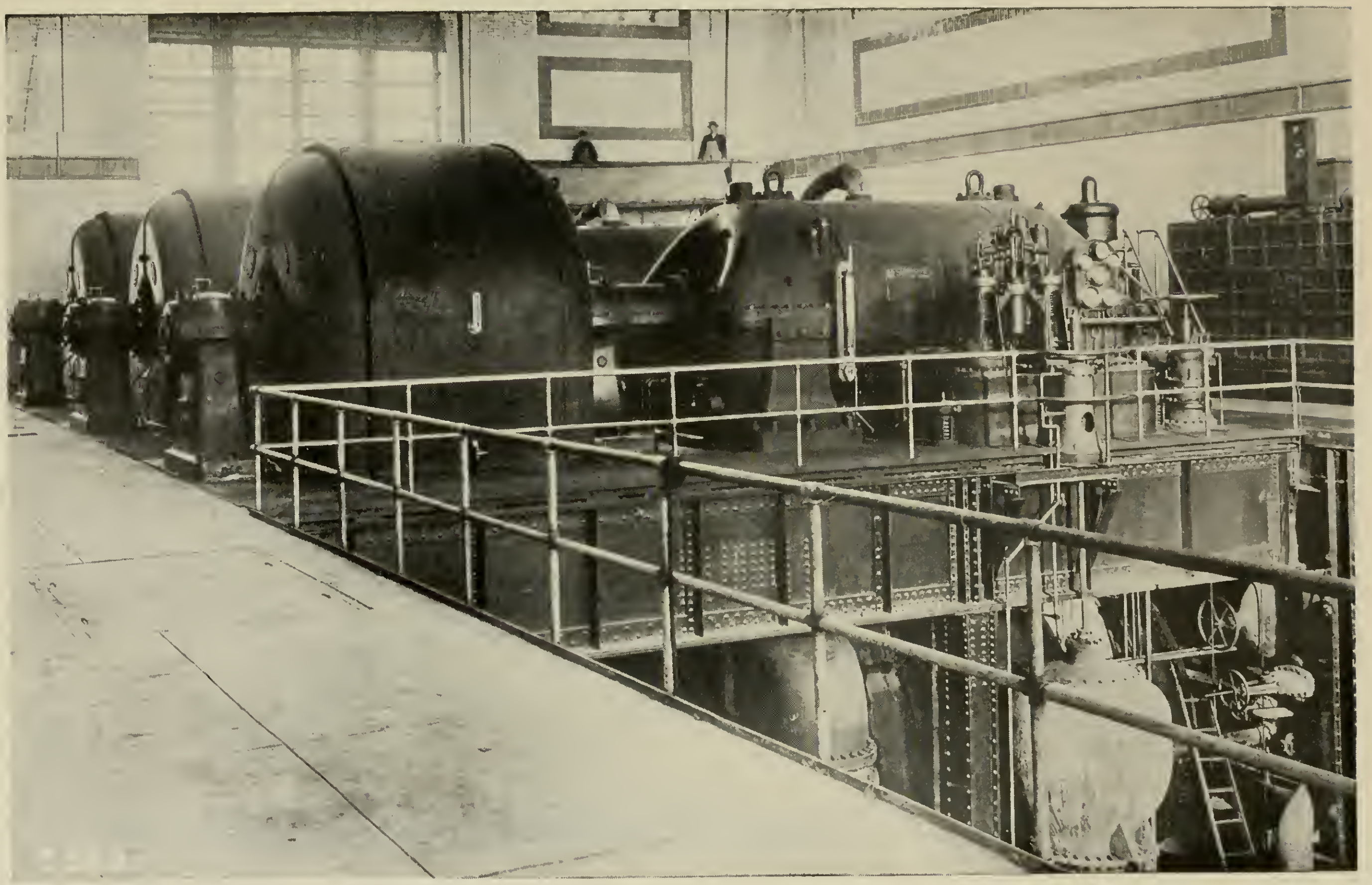


Fig. 67. Complete Panel Board in Steel Cabinet

Their rules require that switches have sufficient metal for the necessary mechanical strength, and that the temperature rise shall not be more than 28 degrees centigrade above the surrounding air, when carrying full rated load continuously. With good contacts they allow a rated current density of 75 amperes for each square inch of contact area. Switches of over 30 amperes must be provided with terminal lugs screwed or bolted into the switch into which the



THREE 19,000-K.V.A. THREE-PHASE 8000-VOLT UNITS. INSTALLED FOR THE UNITED ELECTRIC LIGHT AND POWER COMPANY, NEW YORK

Courtesy of Westinghouse Machine Company

conducting wires must be soldered. In practice, lever switches of less than 30-ampere capacity are seldom manufactured and, on that size, lugs are usually furnished.

Lever switches should be mounted on non-absorptive non-combustible insulating bases or panels such as slate, marble, or porcelain. Where switches are mounted on bases which are to be placed against a flat surface, the connection must be made at the front of the switch. In this case the block is extended far enough so that the terminal can be screwed or bolted on to the face of the block. Where the switches are mounted on switchboard panels, a stud is passed through the panel from the switch block and the terminals are fastened to it by means of nuts.

Lever switches should be mounted so that gravity tends to open them rather than close them. They should be grouped as far as possible for ease of operation. They should be easily accessible and located in a dry place. Modern practice requires that, for small capacities and especially when in exposed places, the group of switches be mounted on a panel board and placed in a steel cabinet properly lined with some material such as slate, Fig. 67.

Plain lever switches are not used for opening circuits under load on more than 300 volts d. c. or 500 volts a. c. However, they may be used on circuits of all voltages for disconnecting purposes at no load or very small load and where any considerable current is ruptured by some other device.

The Underwriters' Rules cover a large number of points of design and construction not mentioned above, but they are of interest principally to the manufacturers, and all reputable manufacturers follow them.

Oil Switches. For alternating-current circuits, especially where the voltage is high, lever switches are not suitable for operation under load. An oil switch is one in which the circuit is made or broken under oil. Fig. 68 shows a single-pole 15,000-volt oil switch for switchboard service, with the oil tank removed. Such switches are mounted back of, or remote from, the panels, and are operated by a handle connected to the switch through a system of links and levers. These switches usually open by gravity, either when tripped by hand or automatically. When tripped automatically by abnormal conditions in the circuit, they are sometimes called "oil circuit breakers". They are manufactured with one or more poles, sometimes with one tank for all poles and sometimes with a separate tank for each pole.

Switches built along the same general lines are also manufactured for mounting on walls or on motor-driven machines and are used for controlling individual motors. In textile mills and other places where the fire risk is great, such switches are almost essential even on low-voltage circuits.

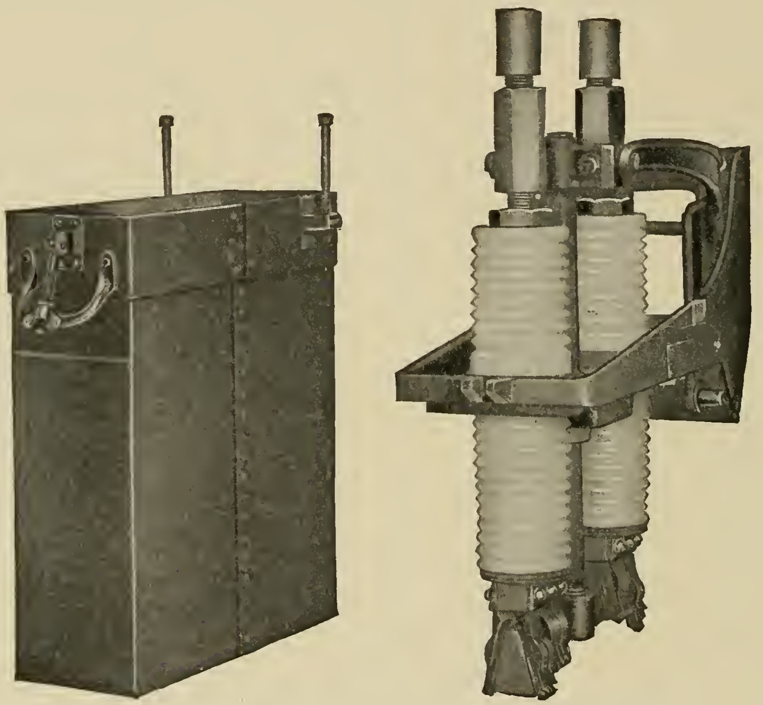


Fig. 68. General Type of Oil Switch with Cover Removed
Courtesy of General Electric Company

Oil switches are not suitable for use on direct-current circuits, since there is no reversal of current and the arc is much harder to extinguish than the a. c. arc.

Circuit Breakers. Where large currents are to be broken, when the voltage is high, or where automatic features are required, the usual direct-current practice is to use circuit breakers. For electric railway service on cars, or in places where the equipment must be totally enclosed, magnetic blowout circuit breakers are still used. These breakers are arranged so that, as the circuit is broken, current is caused to flow in a coil which produces a magnetic field so placed as to draw out the arc and cause it to break quickly.

The most common form of circuit breaker is the carbon-break circuit breaker as illustrated in Fig. 69. This breaker has a copper-leaf brush for continuously carrying the current. As the circuit breaker is opened, or opens automatically, this brush leaves contact first. The current is then temporarily carried by a secondary copper contact which opens second. Last of all the carbon contacts open and actually break the circuit. This arrangement insures that the burning will all come on the renewable carbon block and the main contacts will always be left in good condition.

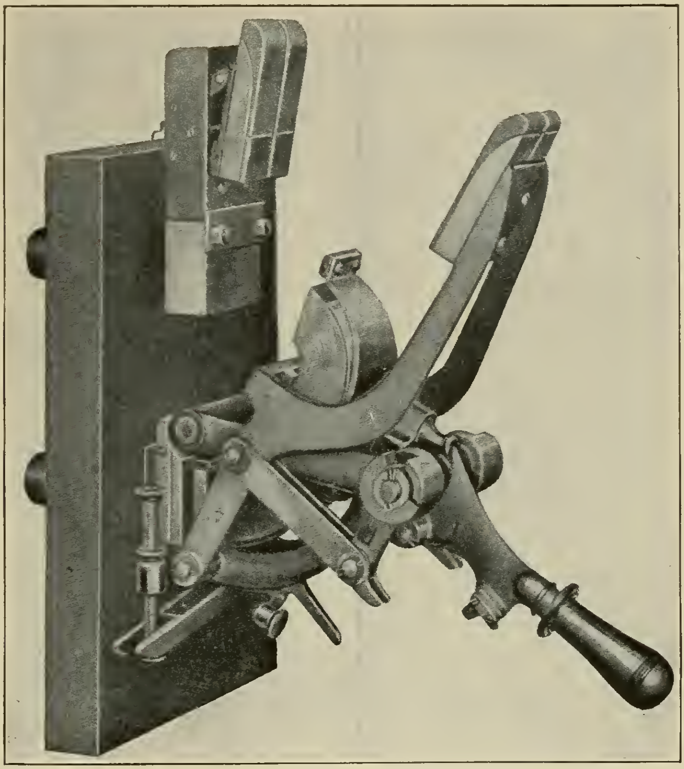


Fig. 69. "Type C" 650-Volt 2000-Ampere Single-Pole Overload Circuit Breaker
Courtesy of General Electric Company

Automatic overload tripping is obtained by arranging a magnetic circuit in such a way that at a predetermined current value an armature will be lifted and, in its movement, will strike a tripping latch which in turn releases the moving element of the breaker so that it opens by gravity and the spring action of the contacts. Other automatic features can also be obtained by means of auxiliary attachments or separate relays acting on the circuit-breaker mechanism in a similar way. Thus the circuit breaker may be tripped by an underload, by low voltage, or by the reversal of current, when desired.

Carbon-break circuit breakers are often used in alternating-current circuits for voltages of 600 and below. They are of the same general appearance as those used in direct-current circuits, and operate on the same principle.

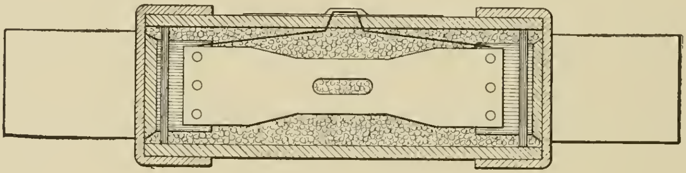


Fig. 70. Section of Enclosed Fuse

Fuses. Because of the great expense of replacements on circuits where trouble is frequent and severe, fuses are being abandoned in favor of circuit breakers for all large power circuits. However, there are so many places where fuses have the advantage, because they are simpler, that they may still be considered among the most important protective devices used.

A fuse is merely a strip of metal, inserted in a circuit, of such cross section that at a given current it will melt, thus opening the circuit. If this fuse is made so that its ultimate carrying capacity is less than the safe-carrying capacity of the rest of the circuit, it will protect the apparatus against the excessive current. This in general describes the principle and function of the fuse.

The form which a fuse may assume depends upon the severity of the service, the capacity of the circuit, and the voltage. Figs. 70, 71, and 72 show, respectively, a section of a National Electric Code

Standard enclosed fuse, an open-link fuse, and an expulsion fuse for higher voltage a. c. circuits.

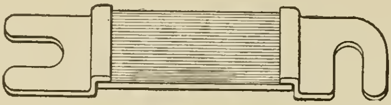


Fig. 71. Open-Link Fuse

Open-link fuses are, as the name implies, merely links of metal with limited current-carrying capacity, which are mounted between two terminal blocks and fastened to them by bolts or screws. The metal used is usually an alloy of special composition for the service. The National Board of Fire Underwriters requires that the fuses be stamped with about 80 per cent of the maximum current which they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts. The minimum current which will melt the fuse in about five minutes is taken as the melting point.

It can readily be seen that on circuits of large capacity, or circuits having a large generating capacity back of them, the opening of an open-link fuse would produce a heavy flash and a dangerous splashing of metal. The use of enclosed fuses on circuits of from 30- to 600-ampere capacity has become almost universal and this practice is to be recommended in any case where fuses are obtainable which meet the rules of the Underwriters. The Underwriters' Rules cover the general construction, performance, and dimensions of fuses within the range of capacities given above.

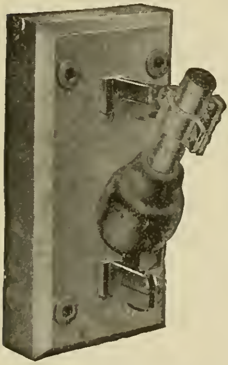


Fig. 72. General Electric Single-Pole Expulsion Fuse Block

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross section to insure mechanical stiffness and carrying capacity.

For higher voltage circuits used in alternating current, the open fuse has the same objections as for direct current and in a more marked degree. The completely enclosed fuse is also found unsatisfactory. It has, therefore, been necessary to adopt a different principle of operation for these fuses. The link of metal used for the fuse is enclosed in a tube which has an enlarged section at one end and is open at the other end. The reduced section of the fuse is placed so as to come within the enlarged section, or explosion chamber of the tube. When the fuse is ruptured, gases form in the explosion chamber which blow out through the tube, thus opening the circuit quickly and effectively.

As a general proposition, fuses of any kind are superfluous or undesirable where the conditions warrant the use of automatic circuit breakers, as in power houses, sub-stations, and factories. The conditions which should be met in the manufacture of a good fuse are as follows:

(1) They should melt at a definite current.
(2) The melting point should not change due to time, current, heating, or any reasonable service conditions.
(3) They should act quickly at the current for which they are marked.
(4) They should give firm and lasting contacts with the terminal blocks to which they are attached.

While the above conditions are hard to meet and perfect fuses cannot be expected, they do give a fair degree of protection and will continue to be used for many classes of service.

ELECTRICAL RESISTANCE

Among the most important tests which it is necessary to make in connection with dynamo-electric machinery are those for resistance. There are two principal classes of resistance tests that must be made in connection with generators and motors: *first,* the resistance of the wires or conductors themselves, called the *metallic* resistance; and *second,* the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

Metallic Resistance

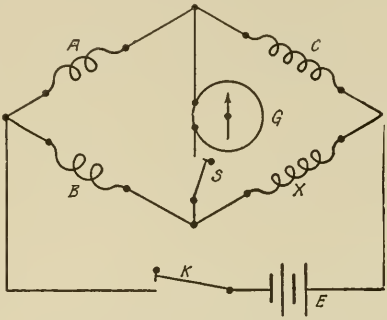


Fig. 73. Wheatstone Bridge Diagram

Wheatstone Bridge Method. The Wheatstone bridge is simply a number of branch circuits connected as indicated in Fig. 73. *A, B,* and *C* are resistances the values of which are known. *X* is the resistance which is being measured. *G* is a galvanometer, *S* its key, and *E* is a battery of one or two cells controlled by a key *K,* all being connected as shown. The resistance *C* is varied until the galvanometer shows no deflection when the keys *K* and *S* are closed in the order named. If the key *S* should be closed before *K*, or at the same moment, the inductive effect might produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance *X* is then found by multiplying together resistances *C* and *B,* and dividing by *A;* that is,

$$X = \frac{CB}{A}$$

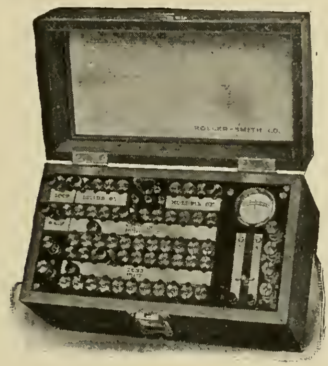


Fig. 74. Portable Wheatstone Bridge
Courtesy of Roller-Smith Company

Portable Bridge. A very convenient form of this apparatus is what is known as the portable bridge, Fig. 74. This consists of a plug resistance box of the decade type, corresponding to *C* of Fig. 73; the ratio coils corresponding to *A* and *B* of Fig. 73, four of these coils being multipliers and four dividers, giving a theoretical range from .001 ohms to over 11 megohms; sensitive galvanometer, battery, keys, etc. The resistance coils are of zero temperature coefficient and are noninductively wound. For the method of operation, the reader is referred to the article on Electrical Measurements. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

Where the resistance of a generator armature, say, is too high for accurate bridge measurements, recourse may be had to an ohmmeter, or a bridge megger, both instruments of which are described in the article on Electrical Measurements. The method described in the following paragraph is also available.

Drop, or Fall-of-Potential, Method. The fall-of-potential method is well adapted for locating faults quickly and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This method consists in passing a current through the armature and connections and a known resistance of say 1/100 ohm, all connected in series, as represented in Fig. 75. The "drop" or fall-of-potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked *1* and *2*), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at *M, N, O, Q, R,* and *S,* so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A resistance is used for limiting the current, which may be obtained from an ordinary 110- or 220-volt source of d.c. supply.

Instead of using a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, viz., *If E is the voltmeter deflection and I represents the amperes flowing, the resistance of the part under test is*

$$R=\frac{E}{I}$$

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, increasing it until a good deflection is obtained on the voltmeter. If a current of several amperes cannot be had, a few cells of storage battery or some strong primary battery can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields, on account of their high resistance, may be tested by the bridge method, or by voltmeter and ammeter readings; while the armature can be tested, as in Fig. 75. Of course it must not be allowed to revolve while its resistance is being tested.

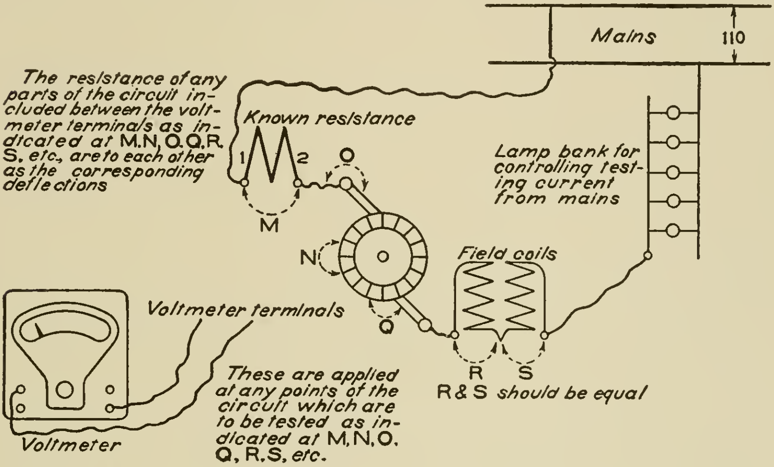

Mains
110
The resistance of any parts of the circuit included between the voltmeter terminals as indicated at M.N.O.Q.R.S. etc., are to each other as the corresponding deflections
Known resistance
1
2
O
M
N
O
Lamp bank for controlling testing current from mains
Field coils
Voltmeter terminals
Q
R
S
R & S should be equal
These are applied at any points of the circuit which are to be tested as indicated at M.N.O.Q.R.S. etc.
Voltmeter

Fig. 75. Wiring Diagram for "Drop" Method of Testing Armature Resistance

The drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines, Fig. 75—for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

Insulation Resistance

The insulation resistance of a generator or motor, that is, the resistance between its conductors and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage. Any value over one megohm in such cases is usually high enough. It is therefore beyond the range of ordinary Wheatstone bridge tests; but two good methods are applicable, the ''direct-deflection'' method and the voltmeter method.

Direct-Deflection Method. The direct-deflection method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 76. The galvanometer should be shunted with the 1/999 coil of the shunt, so that only 1/1000 of the current passes through the galvanometer, the machine being entirely disconnected. The keys *A* and *B* are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number, if necessary, until a considerable deflection is obtained. The circuit is then opened at the key *B* and connected by wires to the binding post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and the battery. The key *A* is then closed and the deflection noted. Probably there will be little or no deflection on account of the high insulation resistance; and the shunt is changed to 1/99, 1/9, or left out entirely, if little deflection is obtained. In changing the shunt, the key should always be open; otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

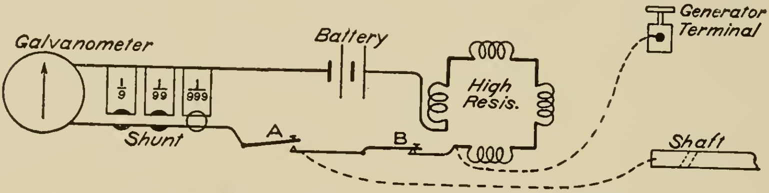


Fig. 76. Wiring Diagram for Direct-Deflection Method

$$\text{Insulation resistance} = \frac{DRS}{d}$$

in which D is the first deflection without the machine connected; d is the deflection with the machine insulation in the circuit; R is the known high resistance; and S is the ratio of the shunted current through the galvanometer. If the shunt is 1/999 in the first test, and 1/9 in the second, S is 100. If the shunt is disconnected entirely in the second test, S is 1000. It is safer to leave the high resistance in circuit in the second test to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated, if it exists.

Voltmeter Method. The voltmeter test for insulation resistance requires a sensitive high-resistance voltmeter. Take, for example, the 150-volt instrument, Fig. 77, which usually has about a 15,000-ohm resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery and measure the voltage. This should be as high as possible, say 100 volts. The insulation resistance of

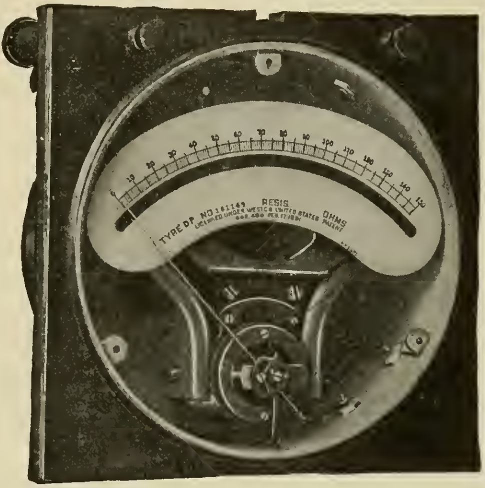


Fig. 77. Typical D'Arsonval Voltmeter
Courtesy of General Electric Company

the machine is then connected into the circuit, as indicated in Fig. 78. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance. The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{DR}{d} - R$$

in which D is the first deflection; d is the second deflection; and R is the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale, say 115 volts. To calculate the scale use the formula

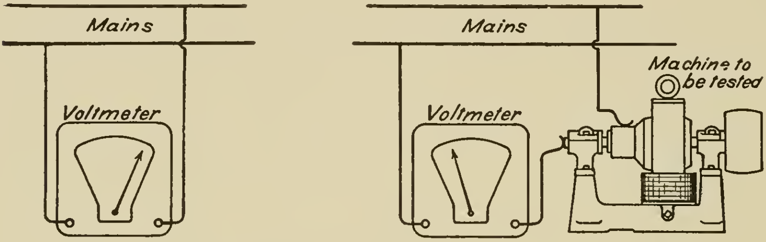


Fig. 78. Wiring Diagram for Insulation Test by Voltmeter Method

$$d = \frac{115\,R}{X+R}$$

in which X is the insulation resistance (1 megohm, $\frac{1}{2}$ megohm, etc.); and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test exceedingly high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms—which is high enough for most practical purposes.

Magneto-Electric Bell. The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine and the other to the frame or shaft. A magneto bell is rated to ring with 10,000 to 30,000 ohms in series with it, and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case, and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine practically grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

DIELECTRIC STRENGTH TESTS

The above methods of determining insulation are given in some detail, since they give a means of testing which can be applied almost any place. However, the ohmic resistance of any insulation is not of first importance. The dielectric strength, that is, the resistance to actual rupture by high voltage current, is considered as much more important. In making such tests, the high voltage should be applied between every circuit of the apparatus and every other circuit, and between every circuit and the material of the machine itself.

Test Voltages for Different Sized Machines. The rules of the American Institute of Electrical Engineers recommend that the proper voltage to be used for testing machines in general shall be twice the normal voltage of the circuit to which they are connected, plus 1000 volts. There are a few exceptions.

Conditions of Test. The machine should be tested with an alternating voltage of a virtual value (the ordinary a. c. voltmeter gives this value very closely), as given above. The frequency is not important on direct-current apparatus or on alternating-current apparatus of small capacity. However, on large a. c. machines the frequency should be the same as the normal frequency at which the machine is to operate.

Before being given high potential tests, all machines should be completely assembled, should be clean and in good running condition, and should be at a temperature corresponding to full load on the machine. The rules of the A. I. E. E. specify that the high-potential tests shall ordinarily be made in the factory of the manufacturer. A number of other rules are given in regard to ''methods of testing'', ''methods of measuring the test voltage'', and ''apparatus for supplying the test voltage''. These rules are followed almost universally in the United States today, as are the other rules of the A. I. E. E.

VOLTAGE

Voltmeter. An instrument used to measure the pressure or voltage of a circuit is called a voltmeter, Fig. 77. It is usually a galvanometer of practically constant resistance. The moving element carries a pointer which moves over a graduated scale. This scale is marked directly in volts or millivolts. A voltmeter should have a very high resistance in order that the indications may always be accurate and that the instrument may take as little current as possible. It should be shielded so that it will not be affected by stray fields due to magnets or currents flowing in conductors close to the instrument.

Test Method. The voltage of any machine or circuit is tested by merely connecting the two terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main terminals or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the *difference of potential,* or *terminal voltage,* and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from zero to full load. This is due to the i. r. drop caused by the resistance of the armature circuit, which, in turn, weakens the field current and magnetism. Armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. Compound-wound generators may be designed to give practically constant voltage from no load to full load, or they may be designed to rise any desired percentage of ''over-compounding'' from no load to full load.

CURRENT

Instruments for measuring current are called ''ammeters''. These instruments are built on the same general principle as a voltmeter, except that the main line current or a shunted part of it passes through the instrument.

Ammeter Always Connected in Series with Line. In testing the current of a generator or motor, it is necessary only to connect an ammeter of the proper range in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current, or series-wound, machine the same current flows through all parts as well as through the circuit; consequently the measurement of current is very simple.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, give the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be calculated from its diameter measured with a screw caliper or a wire gage, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge, Fig. 74.

The above methods will seldom be found necessary in modern plants of any kind, since good portable ammeters are now so cheap as to be included in the equipment of nearly all such plants. In many industrial plants, especially those using alternating current, it is the practice to put an ammeter on each motor circuit permanently. In central stations all machines and most feeder circuits are provided with ammeters for reading the line current.

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* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit and another in the circuit from the starting box to the independent armature terminal.

Water Box for Testing Generators. In testing a generator at full load it is often difficult to find a means of disposing of the current generated. Any metallic resistance designed to absorb the entire output of a large generator would be out of the question because of the expense. If there is no way to absorb the power by connecting the machine to actually loaded distributing lines, a water box forms the cheapest means. The size of the box will, of course, depend upon the size of the machine to be tested. For machines of medium size a tub, barrel, or hogshead may be used. This is filled with water, and salt or common baking soda added until the proper current is obtained when the terminals are lowered into it. These terminals are usually two plates of iron to which the main conductors are attached. This arrangement allows the current to be varied by raising and lowering the plates, by adjusting the distance between plates, or by changing the strength of the solution. Alternating-current generators, when tested in this way, will require two, three, or four plates, depending on whether they are single-phase, three-phase, or two-phase.

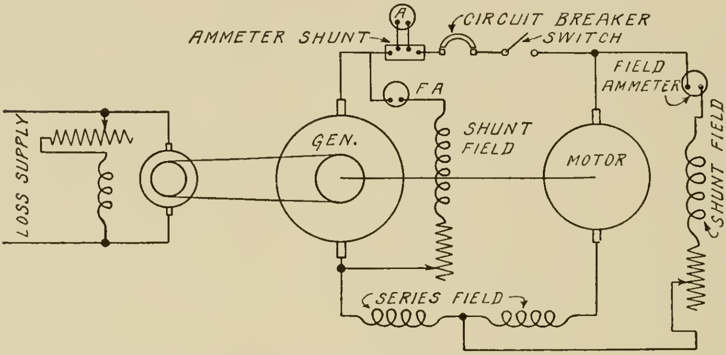
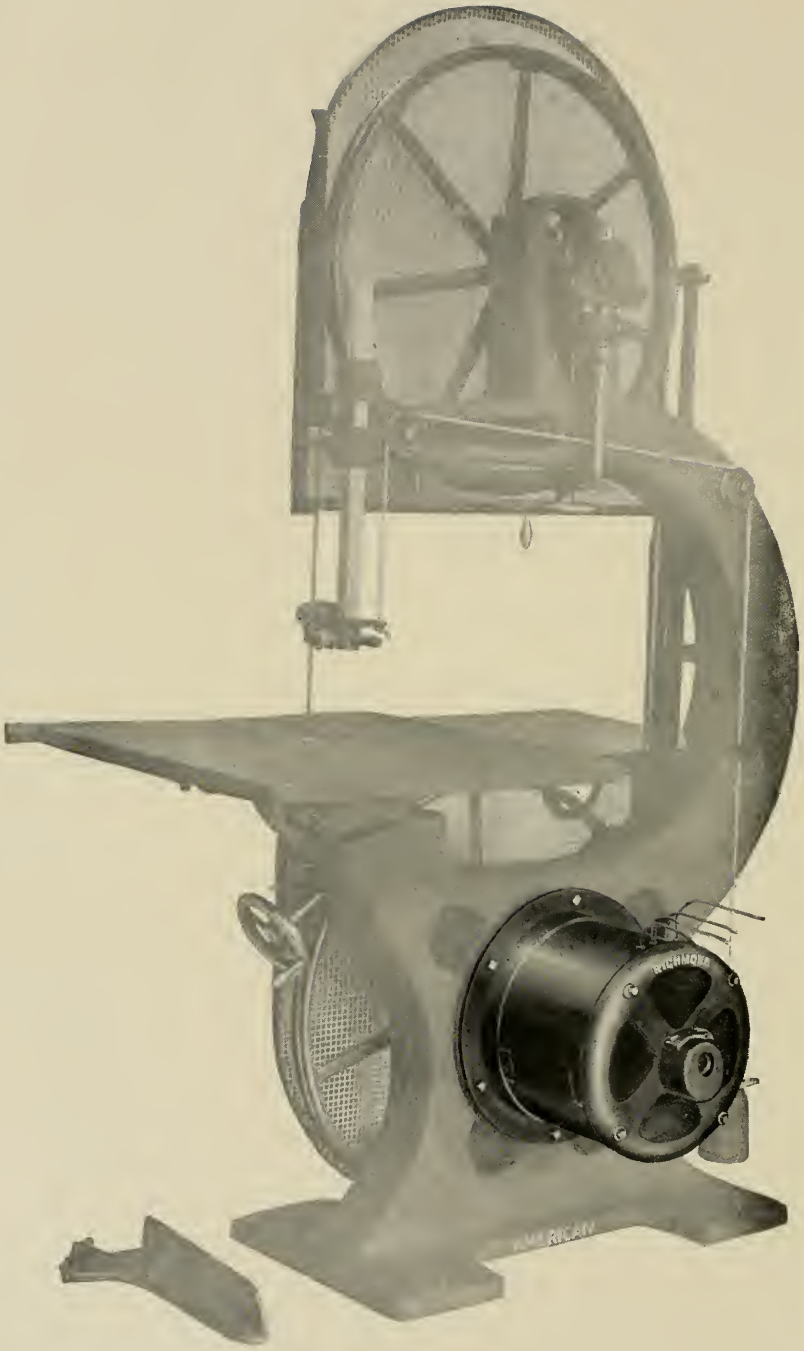


Fig. 79. Wiring Diagram for "Pump Back" Testing Method with Mechanical Loss Supply

"Pump Back" Method. In some cases, where duplicate machines are to be tested, another method is available. The two



RICHMOND POLYPHASE MOTOR DIRECT CONNECTED TO BAND SAW
Courtesy of Richmond Electric Company

machines are connected together both electrically and mechanically. Thus one machine, acting as a motor, drives the second machine mechanically; while the second machine, acting as a generator, drives the first machine electrically. Of course such a combination must be supplied with some other power to furnish the losses in the two machines. This can be done by belting another motor, operated from an outside source, to the two machines in test, Fig. 79.

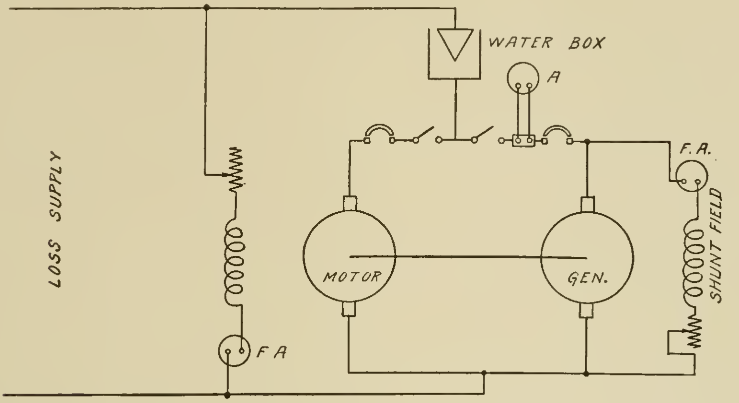


Fig. 80. Wiring Diagram for "Pump Back" Testing Method with Electrical Loss Supply

This auxiliary motor may be comparatively small since it supplies the losses only. With such an arrangement, one of the machines can be given full load and tested completely without the use of water boxes and without requiring a large amount of power to operate it.

In another of the "pump back" methods, there is an electrical loss supply instead of a mechanical loss supply. Fig. 80 shows the method of wiring the machines for such a test.

Similar methods may be employed for testing duplicate a. c. machines. Modification will have to be made, of course, to take care of the difference in the character of the current.

SPEED

Speed Counter. Speed is usually measured by the well-known speed counter, Fig. 81, consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

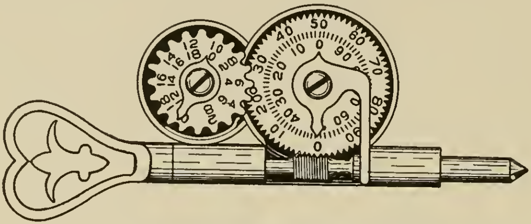


Fig. 81. Typical Speed Counter

Tachometer. Another instrument for testing the number of revolutions per minute is the tachometer. The stationary form of this instrument is shown in Fig. 82. It must be belted by a string, tape, or light leather belt to the machine, the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument, Fig. 83, is applied directly to the end of the shaft of the machine, like the speed counter, a sliding gear shifter providing the required range of speeds. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

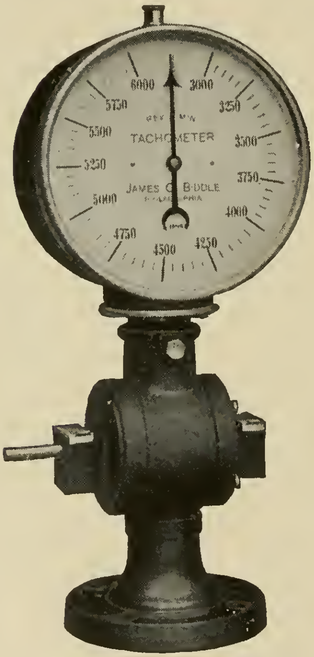


Fig. 82. Stationary Form of Tachometer

Courtesy of James G. Biddle, Philadelphia

Electric Tachometer. Another instrument which gives a direct reading of revolutions per minute is the electric tachometer. This instrument consists of a small generator, which is driven by the revolving shaft, and a voltmeter connected across the terminals of this generator. The design is such that the voltage of the generator is proportional to its speed. The voltmeter is calibrated in revolutions per minute and is, therefore, a direct-reading tachometer.

A simple way to test the speed of a belted machine in revolutions per minute is to make a large black or white mark on the belt and note how many times the mark passes per minute; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip; for example, in the case of the tape belt just referred to, this belt should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine. The belt should not have much elasticity like a rubber band, as it would give an incorrect result.

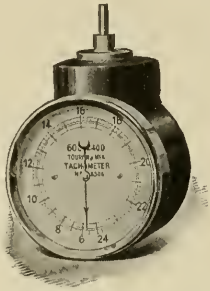


Fig. 83. Hand Tachometer

Courtesy of James G. Biddle

TORQUE

Prony Brake. Torque, or pull, is measured in the case of a motor by the use of a Prony or strap brake. The former consists of a lever $L L$ of wood, clamped on the pulley of the machine to be tested, as indicated in Fig. 84. The pressure of the screws $S S$ is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws S S until the motor draws its full current, as indicated by an ammeter. The full-load current is usually marked on the name plate of the motor. If it is not known, the following formulas may be used:

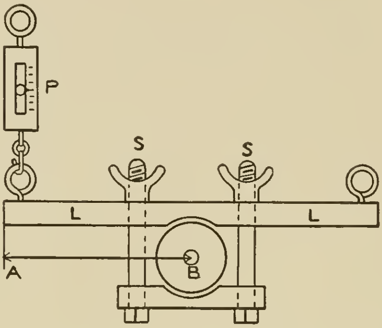


Fig. 84. Diagram of Prony Brake

For d. c. motors:

$$\text{Current} = \frac{\text{h.p.} \times 746}{\text{Volts} \times \text{Efficiency}}$$

For single phase a. c. motors:

$$\text{Current} = \frac{\text{h.p.} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor}}$$

For three-phase a. c. motors:

$$\text{Current} = \frac{\text{h.p.} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor} \times 1.73}$$

For two-phase a. c. motors:

$$\text{Current} = \frac{\text{h.p.} \times 746}{\text{Volts} \times \text{Efficiency} \times \text{Power Factor} \times 2}$$

The efficiency and the power factor in these formulas should always be expressed as decimals. When the rating is given in kw., instead of h. p., this rating multiplied by 1000 should be substituted instead of h. p. × 746.

The torque or pull is measured by known weights or, more conveniently, by a spring balance *P*. If desired, the test may also be made at three-quarters, one-half, or any other fraction of the full-load current.

The torque in foot-pounds, which should be obtained, can also be calculated from the power at which the machine is rated, by the formula:

$$\text{Torque} = \frac{\text{h.p.} \times 33{,}000}{6.28 \times S}$$

or

$$P = \frac{\text{h.p.} \times 33{,}000}{2\pi r \times S}$$

in which h.p. is the horsepower of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius. One h.p. produced at a speed of 1000 revolutions requires a pull of 5.25 pounds at the end of a 1-foot lever; at 500 revolutions, twice as much; at 2000 revolutions, half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

Torque of a Generator. The torque of a generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor and testing it by the friction brake, as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

POWER

Electrical Power. The electrical power of a generator or motor is found by testing the voltage and the current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horsepower by dividing by 746, and into kilowatts by dividing by 1000.

Mechanical Power. The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

$$\text{Horsepower} = \frac{P \times S \times 6.28 \times R}{33{,}000}$$

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* In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

in which P is the pull in pounds; S is the speed in revolutions per minute; and R is the radius in feet at which P is measured.

Efficiency

Analysis of Definition. The efficiency is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}$$

Efficiency of D.C. Generators. *Outline of Method.* In testing the efficiency of d. c. generators there are several methods which can be followed. One large manufacturer has adopted the "measurement of losses" method, and it is probably one of the best for machines of all sizes. In this method the following quantities are measured:

Voltage of the line
Current in the line
Current in the shunt field
Current in the armature
Current in the series field
Current in the series field shunt
Resistance of the brush contact
Resistance of the shunt field (hot)
Resistance of the armature (hot)
Resistance of the series field (hot)
Resistance of the series field shunt (hot)
Core loss
Brush friction loss
Bearing friction loss

Core-Loss and Friction Test. These last three items are determined by a separate test in the following manner: Drive the generator by a small motor, say 10 per cent of the capacity of the generator. Belt drive is usually satisfactory but, if great accuracy is necessary, the motor should be direct-connected to the generator. The motor should not have to carry more than 50 per cent of its full-load rating with maximum field strength on the generator. The motor should be run at its normal speed and field strength as nearly as possible. The resistance of the motor armature should be known. The field strength must be kept *constant* at about normal value. The speed of the motor can be varied by changing the voltage across its armature. The motor and the generator should be run for some time to allow all friction conditions to become constant. Readings should be obtained as follows:

Input to the motor with all brushes down and no field on the generator.

Input to the motor with all brushes raised and no field on the generator.

(The difference in the above gives the loss in brush friction.)

Input to the motor with various values of field current in the generator from zero up to such a value as will give voltage considerably above normal.

Input to the motor while running free with the same field strength as used during the balance of the test.

The speed must be held absolutely constant and no readings taken when the speed is changing in either direction. It is readily seen that by correcting the input to the motor to allow for the I^2R loss in the armature, and for the input to the motor with no field on the generator, we can get the core loss at the different field strengths.

Final Efficiency. We can now add the I^2R losses in the different sections of the electric circuits to the core loss and the friction losses, and obtain the total loss in the generator. The total input then becomes:

$$W_1 = W_o + L$$

$$E = \frac{W_o}{W_1} = \frac{W_o}{W_o + L}$$

in which W_1 is watts input; W_0 is watts output; L is total loss in watts; and E is efficiency.

These losses might have values somewhat as given below for a 20 kw. generator:

Core loss	about 3%
Bearing friction and windage	about 2½%
Brush friction	about ½%
I^2R losses	about 2 to 4%

This would mean an efficiency of about 91 or 92 per cent. The losses given above can be further divided, but such division is not usually necessary. It is to be noted that there are in practice additional losses called "load losses", very difficult to measure. These are usually about 1 or 2 per cent. The method described above can be used for any direct-current machine.

Efficiency of A. C. Generators. For a. c. machines a similar method is used, but in addition to the open-circuit core loss, the core loss is measured with the armature short-circuited and sufficient field to give normal armature current. The total losses obtained are added to the output to obtain the input the same as for d. c. machines, and the efficiencies are obtained in the same way.

Efficiency of Motor-Generators and Converters. The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former. These electrical methods of testing are preferable to mechanical, for the reason that the volts and the amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are more difficult, and not so accurate, but brake tests give good practical results.

Measurement of Power in A. C. Circuits

In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the e. m. f. and, therefore, the product *volts × amperes* is not the true power.

Indicating Wattmeter Method. There are several means for determining the true power of an a. c. circuit, the simplest being an indicating wattmeter. A wattmeter is an electrodynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large noninductive resistance, so that the time constant of the fine-wire circuit is extremely small, and hence its impedance is practically equal to its resistance; the current in, and the resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these two fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it will read directly in watts.

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* When alternating-current machinery is being tested, use wattmeters.

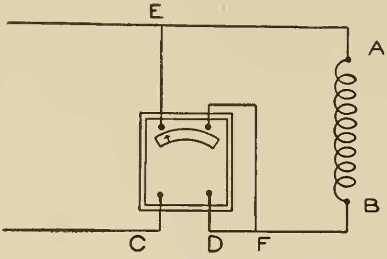

Fig. 85. Wiring Diagram for Determining Input by Indicating Wattmeter Method in Single-Phase Circuit

Single-Phase Circuit. In Fig. 85, *A B* represents an inductive load—say of a single-phase motor—of which the power input is to be determined; *C D*, the terminals of the thick-wire coil (current-coil) of the wattmeter; and *E F*, the voltage- or pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly in watts the power supplied.

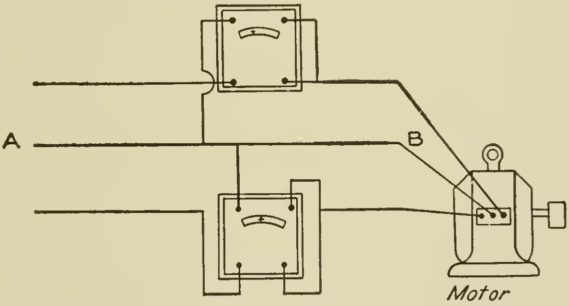

Fig. 86. Wiring Diagram for Testing Power Input in Two-Phase Circuit

Two-Phase Circuit. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, as shown in Fig. 85, and adding the two readings. If the motor be connected up as shown in Fig. 86,* where *A B* forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the outside mains;* and the power supplied is equal to the sum of the two wattmeter readings.

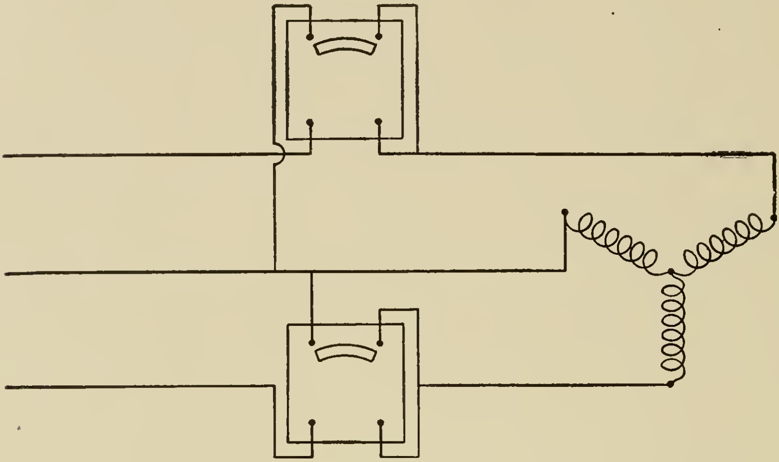

Fig. 87. Power Input Diagram for Three-Phase Circuit, Star-Connected

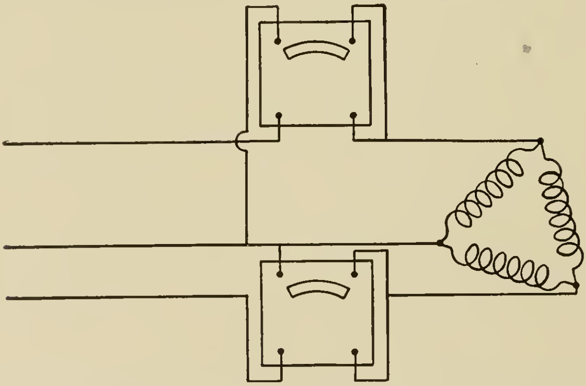

Fig. 88. Power Input Diagram for Three-Phase Circuit, Delta-Connected

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* This form of connection is possible only when the generator has two independent windings, one for each phase.

Three-Phase Circuit. The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as shown in Figs. 87 and 88. The current-carrying coils are placed in series with two of the wires and the pressure coils, respectively, connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively. It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect positively; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

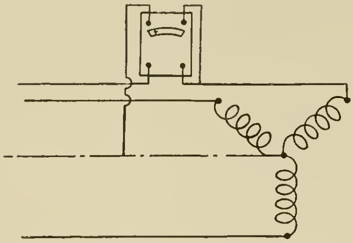


Fig. 89. Power Input Diagram for a Four-Wire Three-Phase Circuit with One Wattmeter

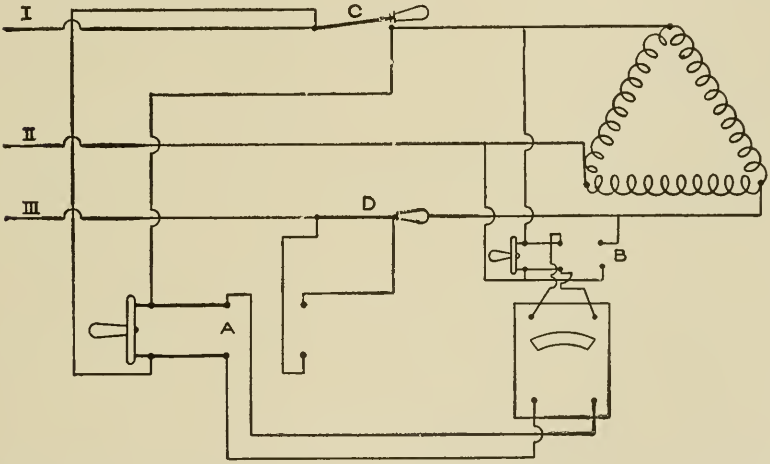


Fig. 90. Power Input Diagram for a Three-Phase Three-Wire Circuit with One Wattmeter

Balanced Four-Wire Three-Phase Circuit. To measure the power of a balanced four-wire three-phase system, one wattmeter may be connected as shown in Fig. 89, and the wattmeter reading multiplied by 3. Usually, however, a four-wire three-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase the power supplied being equal to the algebraic sum of all three readings.

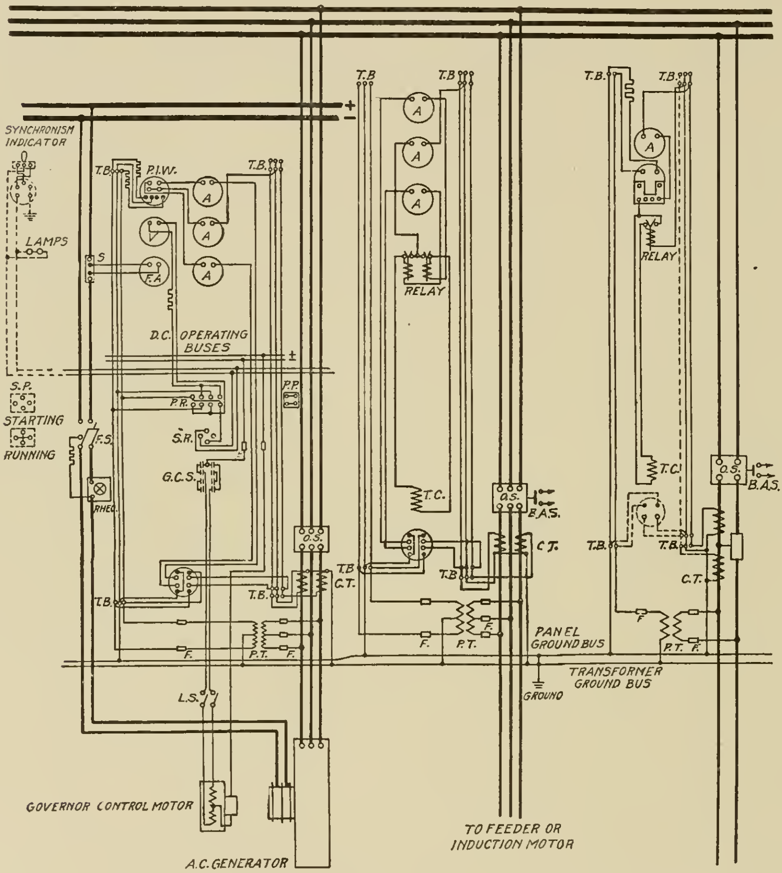


Fig. 91. Wiring Diagram for Switchboard Equipment of Standard Central Station

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are used. Assuming, for example, the three-phase three-wire case, one wattmeter would require switch connections as shown in Fig. 90. A is a double-pole switch which, when thrown to the left, places the current coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch *B* changes the pressure terminals from between machines I and II to machines III and II; while switches *C* and *D* are short-circuiting switches. One of these switches is closed previous to removing the current coil from one phase to the other, and the other one is opened after the coil is in the position indicated in the diagram.

In general practice, power in polyphase circuits is measured by polyphase wattmeters. Such an instrument is merely a combination of two or three single-phase instruments. Thus for two-phase non-interconnected systems, two single-phase elements are mounted together with the two moving elements mounted on the same shaft and carrying one pointer. Thus the movement of the pointer is caused by the combined torque of the two elements and the indication on the scale is equal to the algebraic sum of the two.

Three elements could be combined in the same way for three-phase four-wire circuits. In practice a third current element is customarily added to the usual two of a three-wire instrument. This third coil is divided, each half of it being placed so as to act with one of the two potential coils. This arrangement does not give an absolutely correct indication, but the error is so small that it does not throw the indications outside the limits of commercial accuracy.

Instrument Transformers. In a great many cases in modern practice it is necessary to use instrument transformers. Where the current involved is more than 200 or 300 amperes, or in some cases even less, the instruments can not be made to carry the full amount and current transformers are used to step the current down. The secondary current is usually 5 amperes. Where the voltage is more than 1100, both current and potential transformers are usually used, even for small currents, since it is not safe to bring high voltage directly into the instrument. Fig. 91 shows the wiring diagram of a standard central station switchboard in which the instruments are operated from current and potential transformers.

LOCALIZATION AND REMEDY OF TROUBLES

General Plan. The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with will always have much to do with the success of a plant. A list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the "Table of Troubles" in such a way as to distinguish it from all the others. Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a terminal, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed in its most important features will facilitate the understanding and use of the table.

USE OF TABLE OF TROUBLES

In the use of the Table of Troubles the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, one should take general precautions and preventive measures before any troubles occur, if possible, rather than wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that there is oil in the bearings. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine, if possible, when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down altogether; therefore spare apparatus should always be ready. The continued use of defective machinery is a common but very objectionable practice.

Classification of Troubles. The general plan of the table is to divide all troubles that may occur to generators or motors into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, viz:

Table of Troubles

I. Sparking at Commutator
II. Heating of Commutator and Brushes
III. Heating of Armature
IV. Heating of Field Magnets
V. Heating of Bearings
VI. Noisy Operation
VII. Speed Not Right
VIII. Motor Stops or Fails to Start
IX. Dynamo Fails to Generate
X. Voltage Not Right

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce two effects, and, *vice versa,* one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case, it is well to read through the entire table and note what causes can possibly apply. Generally, there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

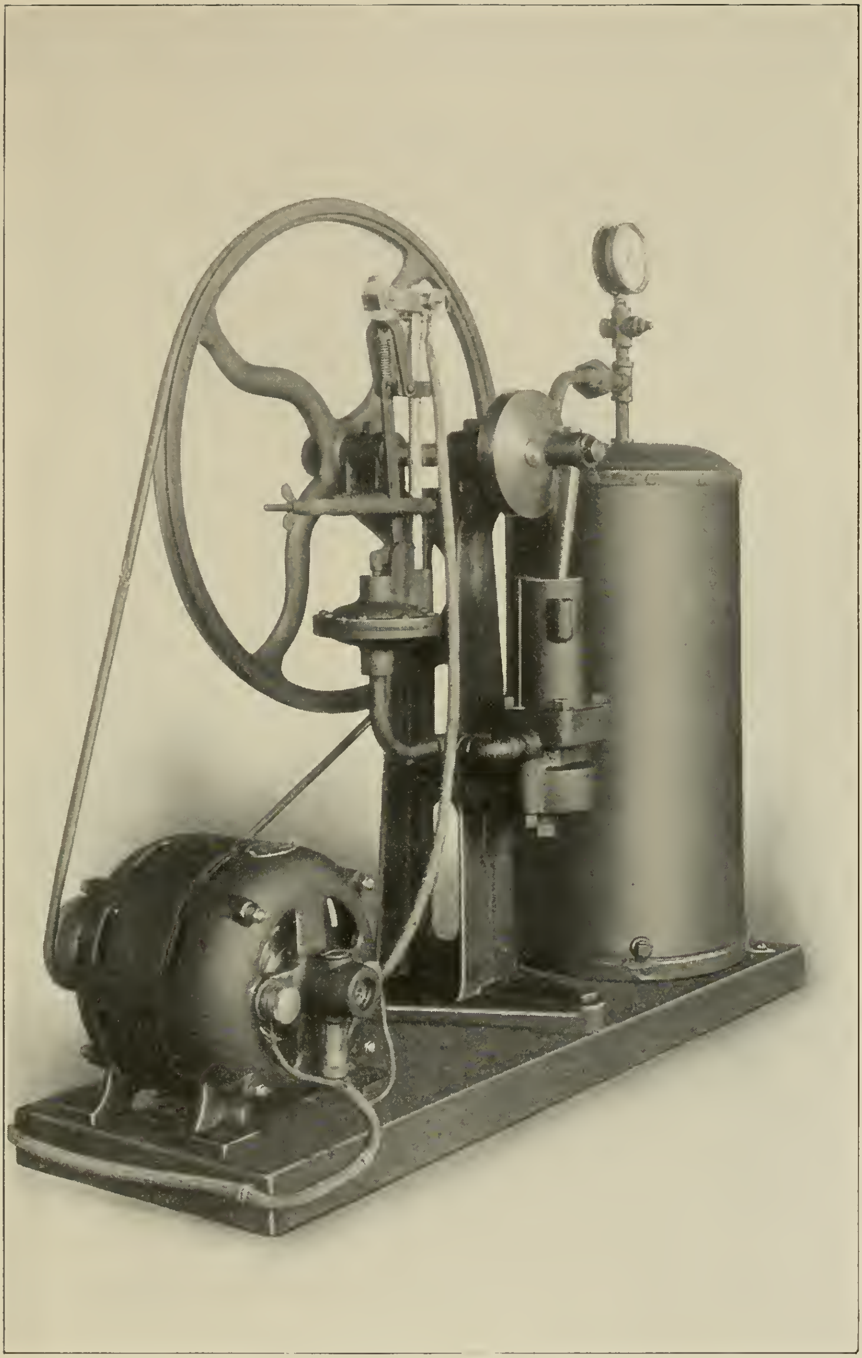
I. SPARKING AT COMMUTATOR

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator, including practically all direct-current and some alternating-current machines, is liable to have this trouble. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

Cause 1. Armature carrying too much current. This is due to (a) overload (for example, too many lamps, motors, etc., fed by generator, or too much mechanical work done by motor; a short circuit, or ground on the line, may also have the effect of overloading a generator); (b) excessive voltage on a constant-potential circuit, (or excessive amperes on a constant-current circuit). In the case of a motor, any friction, such as armature striking pole pieces, or shaft not turning freely, may have the same effect as overload.

Symptom. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly. (See V and VI, 2.)

Remedy. (a) Reduce the load, or eliminate the short circuit or ground on the line; (b) decrease size of driving pulley; or (c) increase size of driven pulley; (d) decrease magnetic strength of field in the case of a generator, or increase it in the case of a motor. If excess of current can not satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.



AIR COMPRESSOR DRIVEN BY ONE-FOURTH HORSEPOWER SINGLE-PHASE MOTOR WITH CLUTCH ARMATURE

Courtesy of Fort Wayne Electric Works

If the starting or regulating rheostat of a motor has too little resistance it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance.

Cause 2. Brushes not set at proper commutating point.

Symptom. Sparking at the brushes.

Remedy. Brushes should be carefully set on the proper neutral point on the commutator. For non-commutating-pole machines this is either ahead of or behind (depending whether the machine is a generator or a motor) a radial line on the commutator usually passing through the center of the pole piece. This point is found by shifting the brushes from the geometrical or ''mechanical'' neutral so that at no load and normal voltage a slight spark, the size of a pin point, shows at the edge of the brush. This point will usually be the proper full-load running position of the brushes. While the usual position of the brushes is about opposite the center of the pole piece, in some machines it may be opposite the space between adjacent pole pieces, depending on the winding of the armature. If the brushes are set exactly wrong, this will cause a generator to fail to generate, and a motor to fail to start, and will blow the fuse or open the breaker in the latter case. (See IX, 6.)

The proper brush position for commutating-pole generators coincides very closely with the mechanical neutral, and is best determined thus: Remove one brush from a brush holder and in its place insert a fiber brush of similar dimensions. Through this drill two holes, about the size of the lead in a pencil, at such a distance apart that the holes are respectively over the centers of two adjacent commutator-bars. Insert in these holes the lead from a pencil so that the ends of the lead ride lightly on the commutator. To the outer ends connect a low-reading voltmeter, and with normal voltage on the generator move the brush-holder yoke until the voltmeter shows a zero reading. This will be the correct brush position, or ''electrical neutral''.

In the case of a commutating-pole motor, the electrical neutral is determined by shifting the brushes until the same speed is obtained in either direction, with equal value of field current and equal values of voltage.

In the case of all d. c. generators and motors it is of prime importance that the brushes be placed parallel to the commutator-bars, and the various sets of brushes spaced exactly the same distance apart.

Cause 3. Commutator rough, eccentric. The commutator may be rough or eccentric; may have one or more *high bars* projecting above the others; one or more *low bars,* or *projecting mica;* or may have as many *low black spots on the commutator* as there are pairs of poles on the machine. Any one of these may cause the brushes to vibrate or to be actually thrown out of contact with the commutator.

Symptom. Note whether there is a glaze or polish on the commutator which shows smooth operation; touch the revolving commutator with the point of a pencil and any roughness or low or high spots can be detected. In the case of an eccentric commutator careful examination shows a rise or fall of the brushes when the commutator turns slowly, or a chattering of the brush when it is running fast.

Remedy. First, go all over the armature, commutator, and equalizer connections, and test for high resistance joints. If any are found they should at once be soldered. (This applies also to rotary converters.) The proper brush setting and spacing should be checked, also the air gap and magnetic joints on the machine. If the commutator is not in very bad shape it may be ground down with a piece of fine sandstone, or sand or carborundum paper (not emery). This should be fitted to a wood block cut to the same curvature as the commutator.

If the commutator is in very bad shape or is eccentric, the armature should be taken out and put in a lathe and the commutator turned. Large machines are fitted with a slide rest attachment for turning the commutator without removing it.

For turning the commutator, a diamond point tool should be used. Only a fine cut should be taken off each time in order to avoid catching in, or chattering on, the copper bars, which are very tough. The surface is then finished with either a sandstone or fine sandpaper.

In order that the commutator may wear smooth and work well, the armature shaft should move freely back and forth about $\frac{1}{8}$ or $\frac{3}{16}$ of an inch in its bearings while running.

A commutator should have a glaze of a brown color. A very bright or scraped appearance does not indicate the best condition. A light grade of engine oil used sparingly on the commutator is beneficial.

Cause 4. Brushes make poor contact with commutator.

Symptom. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a ''glass-hard'' carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

Remedy. Carefully fit, adjust, or clean brushes until they rest evenly on the commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig, Fig. 92. Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

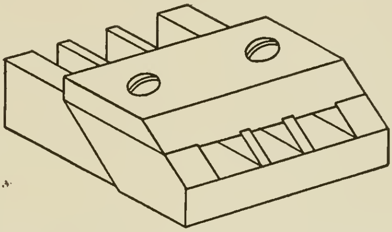


Fig. 92. Typical Jig for Carbon Brushes

Cause 5. Short-circuited or reversed coil or coils in armature.

Symptom. A motor will draw excessive current, even when running free without load. A generator will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw driver or other tool held between the poles near the revolving armature vibrates very perceptibly as the short-circuited coil passes. Almost any armature will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these symptoms being particularly noticeable when several coils are short-circuited or reversed, and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For generators, see IX, 3.

Remedy. A short circuit is often caused by a piece of solder, copper, or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more ''grounds'' in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

Cause 6. Broken circuit in armature.

Symptom. Commutator flashes violently while running, and commutator-bar nearest the break is badly burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of ''high bar'' in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with high bar unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (p. 88) or by a continuity test (p. 93). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself; the break may be repaired or the loose wire fastened or reconnected. If the trouble is due to a broken commutator connection and can not be fixed, the disconnected bar may be temporarily connected to the next by solder. If the break is in the coil itself, rewinding is generally the only cure. The trouble may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator-bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable shut-down. A very rough but quick and simple way to connect two commutator-bars is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

Cause 7. Ground in armature.

Symptom. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

Remedy. A ground can be detected by testing with a magneto bell (p. 92). It can also be located by the drop-of-potential method (p. 88). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound.

Cause 8. Weak field magnetism.

Symptom. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking shifted considerably from normal position owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor high.* A generator fails to generate the full e. m. f. or current.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound generator or motor is often connected wrongly, and will have an opposing effect; that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

Remedy. A break, short circuit, or ground, if external and therefore accessible, is easily repaired. If not accessible, the only remedy is to rewind or replace the faulty coil. A shunt motor will show dangerous sparking if the armature is connected before the field, in starting. In this case the starting-box connections should be changed so that the field is connected before the armature.

If the voltage is too low on a circuit, it may cause sparking in a shunt motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils. (See VII, VIII, IX, and X.)

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* Under some circumstances a shunt motor with a very weak field, or with no field, will run slow, stop, or run backward. The usual and safest assumption is that the speed will increase as the field is weakened, and that with no field the motor may attain such a speed that it will destroy itself. *Never, under any circumstances, should the field circuit be opened when voltage is applied to the terminals.*

Cause 9. Vibration of machine.

Symptom. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

Remedy. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

Cause 10. Chatter of brushes. The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

Symptom. Slight tingling or jarring is felt in brushes.

Remedy. Clean commutator, and oil slightly.

Cause 11. Flying break in armature conductor.

Symptom. No break found by test with armature standing still, but break shown by flashing at brushes when running, being usually due to centrifugal force.

Remedy. Tighten connections to commutator, or repair broken wire, etc.

II TO V. EXCESSIVE HEATING IN GENERATOR OR MOTOR

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is determined, as a rough test, by feeling the parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied *without danger of wetting the other parts.*

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature in an operating machine are given on page 75.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of the machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa.* In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the machine. It is better to make observations for heating by starting the whole machine when cool, which is done by letting it stand for several hours.

II. Heating of Commutator and Brushes

Cause 1. Heat spread from another part of machine.

Symptom. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

Remedy. See III, IV, and V.

Cause 2. Sparking. Any of the causes of sparking will cause heating, which may be slight or serious.

Symptom and Remedy. See I.

Cause 3. Tendency to spark, or slight sparking hardly visible. Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator bars pass under the brushes.

Symptom. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

Remedy. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. (See "Sparking at Commutator", I.) Apply the remedies with extra care. This incipient sparking may be due to incorrect design, which can be corrected only by reconstruction; for example, it may be due to insufficient field strength, and this can be cured by increasing the ampere turns of field winding.

Cause 4. Overheated commutator will decompose carbon brush. The effect is to cover commutator with a black film, which offers resistance and aggravates the heat.

Symptom. Commutator covered with dark coating; commutator, brushes, and holders show marks of abnormal heat.

Remedy. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

Cause 5. Bad connections in brush holder, cable, etc.

Symptom. Holder, cable, etc., feel hottest; abnormal resistance found in these parts by "drop" method.

Remedy. Improve the connections.

Cause 6. Arcing or short circuit in commutator. This may occur across mica or insulation between bars or other parts.

Symptom. Burnt spot between parts; spark appears in the insulation when current is put on.

Remedy. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

Cause 7. Carbon brushes heated by current.

Symptom. Brushes hotter than other parts.

Remedy. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Use larger brushes or a greater number.

III. Heating of Armature

Cause 1. Excessive current in armature coils.

Symptom and Remedy. Symptom and Remedy the same as in case of I, Cause 1.

Cause 2. Short-circuited armature coils.

Symptom and Remedy. Symptom and Remedy the same as in case of I, Cause 5. See also Cause 7.

Cause 3. Moisture in armature coils.

Symptom. The detection of moisture in armature coils is a difficult matter without measuring the insulation resistance. Sometimes a careful inspection of the armature may reveal the presence of moisture, but on large machines the safest method is to apply an insulation test.

Remedy. When the insulation test reveals the presence of moisture, the armature, if small, may be baked in an oven sufficiently warm to expel all moisture, but not hot enough to injure the insulation. If the armature is large it can not readily be removed and placed in an oven. The machine may then be connected to run as a generator or motor, at reduced voltage, in order not to break down the insulation which is weakened by the moisture present, the voltage being gradually brought up as the insulation increases. If more convenient, a current controlled by resistance or otherwise at, say, half of rated value may be sent through a moist armature or field winding to dry it out.

Cause 4. Foucault currents in armature core.

Symptom. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See ''Stray Power Tests''.)

Remedy. Armature core should be laminated more perfectly, which is a matter of first construction.

Cause 5. One or more reversed coils on one side of armature. This will cause a local current to circulate around armature.

Symptom. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each pair of adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor, the half of armature containing the reversed coils is heated more than the others.

Note.—Any excess of current taken by an armature when running *free* as a motor, whatever the cause, must be converted into heat by some defect in the machine; hence the "free current" is the simplest and most complete test of efficiency and perfect condition.

Remedy. Reconnect the coil to agree with the others.

Cause 6. Heat conveyed from other parts.

Symptom. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

Remedy. See II, IV, and V.

Cause 7. Flying cross in armature conductor.

Symptom and Remedy. Symptom and Remedy similar to the case of sparking (I, Cause 11), except that reference here is to the insulation of the conductors.

IV. Heating of Field Magnets

Cause 1. Excessive current in field circuit.

Symptom. Field coils too hot to keep the hand on. Their temperature more than 50 degrees centigrade above that of room by resistance test or by thermometer.

Remedy. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "Drop Method", p. 88.) If the difference is considerable (say, more than 5 or 10 per cent) it is almost a sure sign that one coil is short-circuited or double-grounded.

Cause 2. Foucault currents in pole pieces or field cores.

Symptom. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher, if measured by a thermometer.

Remedy. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces and noting whether it vibrates.

Cause 3. Moisture in field coils.

Symptoms. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines the field takes more than the ordinary current. Field coils steam when hot, or feel moist to the hand. The insulation resistance also tests low.

Remedy. Remove and bake field coils as in the case of small armatures. On large machines the field coils may be connected in parallel-series groups so as to get approximately one-half normal current at reduced voltage. As the insulation resistance rises, the current may be brought up to normal value. (See ''Heating of Armature'', III, 3.)

V. Heating of Bearings

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly while the bearing is flushed with fresh oil, as it might ''freeze''. or stick fast, if stopped entirely.

Cause 1. Lack of oil.

Symptom. Oil reservoir empty. Self-oiling rings fail to turn with shaft. Shaft and bearing look dry, and often there is an odor of hot oil.

Remedy. Loosen bearing cap screws and then retighten them with fingers only. This will give the bearings a little clearance. Open the drain cock on the side of the bearing and pour fresh oil in top of bearing, allowing the oil to run through the bearing until temperature is reduced to a safe value.

Cause 2. Grit or other foreign matter in bearings.

Symptom. Best detected by removing shaft or bearings and examining both. Any grit can, of course, be felt easily, and will also cut the shaft.

Remedy. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. The oil should be perfectly clean; if it is not, it should be filtered.

Cause 3. Shaft rough or cut.

Symptom. Shaft will show grooves or roughness and will probably revolve stiffly.

Remedy. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

Cause 4. Bearings fit too tight.

Symptom. Shaft hard to revolve. Hot spots develop in bearing.

Remedy. Remove the bearing and scrape the spots that show wear; then coat the shaft with a thin layer of red lead and place the bearing on the shaft. Move the bearing back and forth and when it is removed the high spots will be covered with the red lead. These should be scraped off, and the process repeated until a snug-fitting bearing is obtained.

Cause 5. Shaft "sprung" or bent.

Symptom. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

Remedy. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

Cause 6. Bearings out of line.

Symptom. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold the bearings in place, when machine is not running and when belt, if any, is taken off.

Remedy. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then ream the holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

Cause 7. Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.

Symptom. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

Remedy. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

Cause 8. Too great a load or strain on the belt.

Symptom. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 93, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

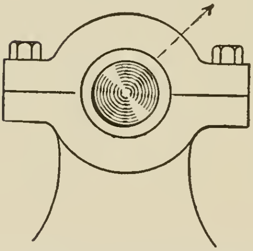


Fig. 93. Diagram Showing Elliptical Bearing Due to Wear

Remedy. Reduce load or tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting", p. 7.)

Cause 9. Armature off of center, producing much greater magnetic pull toward nearer side.

Symptom. Heating of bearing on side where air gap is smallest. Poor commutation due to unequal air gap.

Remedy. The fault is due either to some inherent defect in the machine, to the faces of the poles not being concentric with the armature, to faulty erection of the machine, or to wear on the bearings.

In most cases this trouble can be remedied by raising or lowering either the bearing pedestals or the magnet frame feet, by means of their sheet-iron shims, to obtain the proper air gap vertically. To obtain the correct air gap in a horizontal direction, there is usually enough play in the foundation bolt holes in large machines. On small machines the proper adjustment is usually made by the manufacturer. If the bearings have worn very much it is, of course, advisable to re-babbitt them to restore the correct air gap between armature and fields.

VI. NOISY OPERATION

Cause 1. Vibration due to armature or pulley being out of balance.

Symptom. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

Remedy. Armature or pulley must be perfectly balanced by securely attaching lead or other weights on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them, Fig. 94. If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble". A perfect balance is obtained only when the weights are directly opposite, i.e., in the same line perpendicular to the shaft.

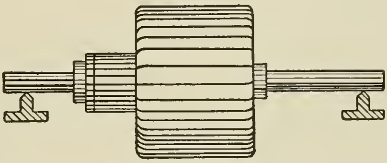


Fig. 94. Method of Putting Armature in Proper Balance

Cause 2. Armature strikes or rubs against pole pieces.

Symptom. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches, or is so close as to be likely to touch, when the machine is running. In small machines, the armature may be turned by hand to find out whether it sticks at any point.

Remedy. See V, 9.

Cause 3. Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.

Symptom. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See V, Cause 7.)

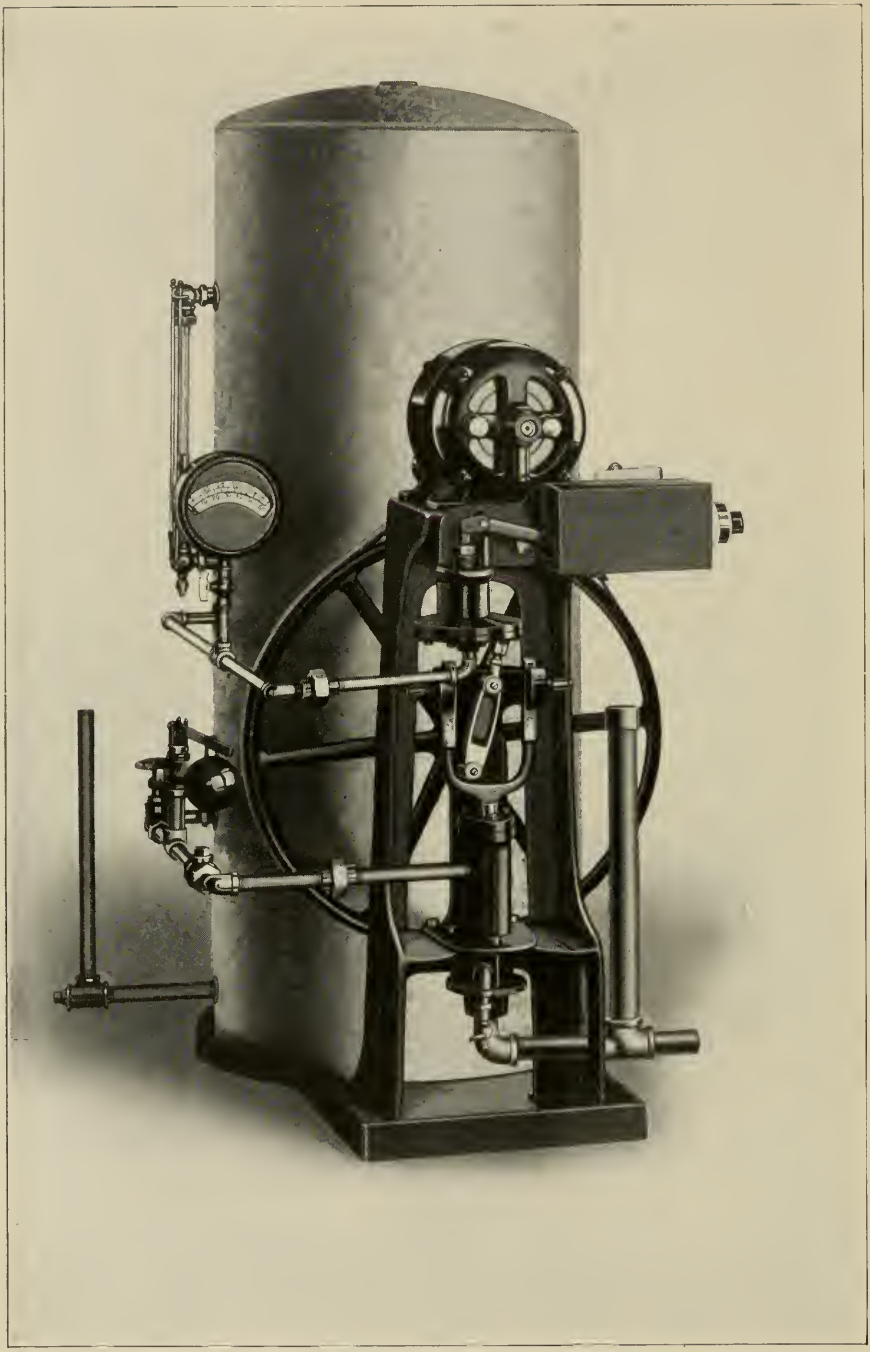
Remedy. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

Cause 4. Rattling due to looseness of screws or other parts.

Symptom. Close examination of the bearings, shaft, pulley, screws, nuts, terminals, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

Cause 5. Singing or hissing of brushes. This is usually occasioned by rough or sticky commutator (see Trouble I, Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasion-



WATER-PUMP EQUIPMENT DRIVEN BY FORT WAYNE FRACTIONAL HORSE-POWER MOTOR

Courtesy of Fort Wayne Electric Works

ally, a new machine will make a noise that is reduced after the machine has been run for some time.

Symptom. Sounds of high pitch are easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time—provided there are two or more brushes in each set, so that the circuit is not opened by lifting a single brush. If there is no current there is, of course, no objection to raising the brushes.

Remedy. Apply a *very little* oil to the commutator with a rag on the end of a stick. Adjust the brushes or smooth the commutator by turning, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This squeaking decreases at full speed, and can generally be stopped altogether by moistening the brushes with oil, care being taken not to have any excess of oil. Running the machine without load for some time usually reduces this trouble.

Cause 6. Flapping or pounding of belt joint or lacing against pulley. (Fig. 95.)

Symptom. Sound repeated twice for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

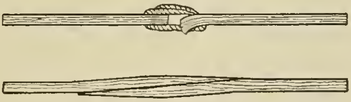


Fig. 95. Typical Bad Belt Joints

Remedy. Endless belt or smoother joint. (See "Belting", p. 8.)

Cause 7. Slipping of belt on pulley due to overload.

Symptom. Intermittent squeaking noise.

Remedy. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion; but such a procedure is a makeshift, is injurious to the belt, and should be adopted only when necessary. (See "Belting", p. 7.)

Cause 8. Humming of armature-core teeth as they pass the pole pieces.

Symptom. Pure humming sound less metallic than Cause 5.

Remedy. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

Cause 9. Humming due to alternating or pulsating current.

Symptom. This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations or to the number of armature teeth passing per second. Usually the latter is considerably greater than the former.

Remedy. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

Note.—It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to place one end of a short stick between the teeth, and press the other end squarely against the various parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED NOT RIGHT

This is generally a serious matter in either a generator or a motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

Speed Too Low

Cause 1. Overload. (See I, Cause 1.)

Symptom. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

Remedy. Reduce the load on machine, increase the diameter of driving pulley, or decrease the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

Cause 2. Short circuit or ground in armature.

Symptom and Remedy. Symptom and remedy the same as in case of III, Cause 2 and Cause 6.

Cause 3. Armature strikes pole pieces.

Symptom and Remedy. Symptom and remedy the same as in the case of VI, Cause 2.

Cause 4. Shaft does not revolve freely in the bearings.

Symptom and Remedy. Symptom and Remedy the same as for V, all cases.

Cause 5. Poor contact in energy circuit. (This applies to single-phase repulsion motors only.)

Symptom. As explained previously, the repulsion motor has one set of brushes short-circuited. These are the energy brushes and if there is a poor contact in this circuit, it will cause a reduction in the output and in the speed of the motor. If this circuit is opened entirely, the motor will stop.

Remedy. Test out this circuit by any resistance method, find the faulty connection, and repair it.

Speed Too High or Too Low

Cause 6. Field magnetism weak. This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded. It makes a generator fail to ''build up'' or excite its field, or give the proper voltage in any case.

Symptom and Remedy. Symptom and remedy the same as in the case of ''Sparking'', Cause 8. (See VII, Cause 7; also IX.)

Cause 7. Too high or too low voltage on the circuit.

Symptom. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

Remedy. The central station or generating plant should be notified that voltage is not right.

Speed Too High

Cause 8. Motor too lightly loaded.

Symptom. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

Remedy. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt- or compound-wound motor should be used, if the load is likely to be thrown off.

Cause 9. Poor contact or open circuit in compensating circuit. (This applies to single-phase repulsion motors only.)

Symptom. No-load speed may be one and one-half times rated speed.

Remedy. Look for poor contact or open circuit and test by resistance method. Repair contact or break.

VIII. MOTOR STOPS OR FAILS TO START

This is an extreme case of the previous class (''Speed Not Right''), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

Cause 1. Great overload. A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or ''stall'' it. (See I, Cause 1.)

Symptom. Of course the chief symptom is the stopping of the motor. On a constant-potential circuit the current is excessive, and safety fuse blows or circuit breaker opens. In their absence or failure, armature is burnt out.

Remedy. Turn off current instantly, reduce or take off the load, replace the fuse or circuit breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

Cause 1a. Load too great (a. c. motors). An induction motor if overloaded will slow down somewhat, and finally stop altogether. It may also fail to start for the same reason. A synchronous motor will maintain its speed with any load it can carry. It will not start under too much load or will pull out of step and stop if overloaded while running.

Symptom. The symptoms may be the same as in Cause 1.

Also there will be a pronounced humming indicating excessive current in the windings.

Remedy. Apply remedies as given in Cause 1.

Cause 2. Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.

Symptom. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See V and VI.)

Remedy. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

Cause 3. Circuit open. This may be due to (a) safety-fuse blown or circuit breaker open; (b) wire in motor broken or slipped out of connections; (c) brushes not in contact with commutator; (d) switch open; (e) circuit supplying motor open; (f) failure at generating plant.

Symptom. Distinguished from Causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential d. c. circuit, the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is very weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

Remedy. Turn off current instantly. Examine safety fuse, circuit breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto, or a cell of battery and an electric bell, to see if there is any break in the circuit. (See "Instructions for Testing", pages 88 to 93.

One of the simplest ways to find whether the circuit has current in it and to locate any break, is to test through an incandescent lamp. Two and five lamps in series should be used on 220- and 500-volt circuits, respectively.

Cause 3a. Circuit open. (a. c. motors.)

Symptom. In an a. c. motor there may be a pronounced humming, showing that there is current in the motor, and yet it will not start. Even with no load the motor will not start, although the rotor may be turned by hand.

Remedy. Turn off current. Check connections external to motor to locate any open circuit. If one phase only is open, allowing only single-phase current to reach the motor, it will not start and the fault can be repaired and the motor started. If no open circuit can be found, try again to start the motor, since the circuit from the power house may have been temporarily interrupted. If the motor still fails to start, the trouble must be from an open circuit within the motor and the usual tests for this condition will have to be made. It may be necessary in this case to remove some coils and replace them with new ones. If it is an induction motor with an external resistance in the rotor circuit, a test should be made for grounds or short circuits in the resistance. Such grounds or shorts can usually be easily found and removed.

In addition to the above, there may be an open circuit in some auxiliary apparatus, such as a transformer or starting compensator. Tests for open circuits should be applied to these auxiliaries as well as to the motor and the breaks or loose connections repaired.

Cause 4. Wrong connection or complete short circuit of field, armature, switch, etc.

General Symptom. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

Symptom on a constant-potential circuit. If current is very great it indicates a short circuit. If the field is at fault it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see "Diagram of Connections" accompanying the machine). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

Symptoms in the three-wire (220-volt direct-current) system. Several peculiar conditions may exist, as follows:

(a) The generator or generators on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside wires will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(b) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(c) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(d) If one of the outside wires becomes accidentally grounded, a 110-volt generator, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

Polyphase Induction Motor Operates Single=Phase

Cause. Open circuit in one lead.

Symptom. Motor will not carry full rated load and heats too much. Motors are often started with the fuses cut out. In that case the motor would start satisfactorily and a blown fuse in one leg would not be discovered. After once up to speed, the motor could be thrown over to running position and would run single-phase, but would carry only a part of its load (about 70 per cent for a three-phase motor).

Remedy. Locate the break in the circuit and replace the fuse or repair the break.

Synchronous Motor Fails to Reach Synchronous Speed

Cause 1. Short-circuited field.

Symptom. Motor starts, but comes up to a speed far below synchronism and sticks at that speed. This speed is not high enough to allow the starting switch to be thrown over into full voltage position.

Remedy. Open the circuit. Examine the revolving field for external short circuits, or shorts in the connections between spools and collector rings. If a resistance is used across the fields in starting, it may be short-circuited, thus shorting the fields. Test the field circuit for grounds which might cause short circuits. Remove any shorts discovered. The motor will then come within about 5 per cent of full speed on the starting tap of the transformer or compensator and can be thrown on full voltage and given current in the fields.

Cause 2. Too much load.

Symptom. The motor may fail entirely to start, or may come up to sub-synchronous speed as in the previous case.

Remedy. Remove some of the load, or arrange a clutch so that the load can be applied after the motor is on the line and running at full speed. If neither of these methods can be used, an auxiliary induction motor may be belted to the motor to help it up to speed.

Synchronous Motor Flashes Across Collector Rings or End Field Coils at Starting

Cause. High voltage induced in fields.

Symptom. When starting switch is first thrown in, a bad flash appears at the collector rings or field coils.

Remedy. Insert a properly designed resistance so that it is across the fields during the starting operation. This resistance will prevent the rise in voltage, which, in some machines, may reach a value as high as 2500 or 3000 volts.

IX. DYNAMO FAILS TO GENERATE

This trouble is almost always caused by the inability of a generator to "build up" or excite its field-magnetism sufficiently. The proper starting of a self-exciting machine requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur on a separately-excited machine; and if it does, it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

Cause 1. Residual magnetism too weak or destroyed.

This may be due to (a) vibration or jar; (b) proximity of another generator; (c) earth's magnetism; (d) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any machine will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries, but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

Symptom. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

Remedy. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator or forward in a motor to make armature magnetism assist field.

Cause 2. Reversed connections or reverse direction of rotation.

Symptom. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in the case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

Remedy. (a) Reverse either armature connections or field connections, *but not both.* (b) Move brushes through 180 degrees for two-pole, 90 degrees for four-pole machines, etc. (c) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case tend to destroy whatever residual magnetism may have been present.

Cause 3. Short circuit in the machine or external circuit. This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

Symptom. Magnetism weak, but still quite perceptible.

Remedy. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short circuit, such as that caused by copper dust on the brush holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking", I, Causes 5 and 8.) Too much load might prevent a shunt dynamo from building up its field magnetism, in which case the load, or some of it, should be disconnected in starting.

Cause 4. Field coils opposed to each other.

Symptom. Upon passing a current from another source of supply, the following symptom will exist: If the pole pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole pieces.

Remedy. Reverse the connections of the incorrectly connected coils in order to make the polarity of the pole pieces opposite. The pole pieces should be alternately north and south.

Cause 5. Open circuit. This may be due to (a) broken wire or faulty connection in machine; (b) brushes not in contact with commutator; (c) safety fuse melted or absent; (d) switch open; (e) external circuit open.

Symptom. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt generator may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

Remedy. Make a very careful examination for open circuit; if not found, test separately the field coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing", p. 92, also VIII, Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or field rheostat of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the external circuit of a series-wound dynamo will prevent it from generating, since the field coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

Cause 6. Brushes not in proper position.

Symptom. The strength of the field increases, and the voltage of the generator builds up.

Remedy. It sometimes happens that brushes are not set at the proper point on commutator and, if the residual magnetism is already weak, the machine may fail to build up. Almost all modern generators made in this country have the brushes set about opposite the center of the pole piece. Generators require the brushes to be shifted in the direction of rotation of the armature; motors require a backward shift to the brushes. Occasionally a generator may be found with armature wound in such a way that the proper position of the brushes is midway between the adjacent pole tips.

X. VOLTAGE OF GENERATOR NOT RIGHT

Cause 1. Speed too low. (See VII.)

Remedy. Increase speed of the prime mover if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

Cause 2. Field magnetism weak.

Symptom and Remedy. See I, Cause 8.

Cause 3. Brushes not in proper position.

Symptom and Remedy. See I, Cause 2.

Cause 4. Machine overloaded.

Symptom and Remedy. See I, Cause 1, and VII, Cause 1; also increase field excitation, if possible.

Cause 5. Short-circuited armature coil or coils.

Symptom and Remedy. See I, Cause 5.

Cause 6. Reversed armature coil or coils.

Symptom and Remedy. See I, Cause 5.

Voltage Too High

Cause 7. Speed too high.

Remedy. Apply the reverse of treatment given in Cause 1.

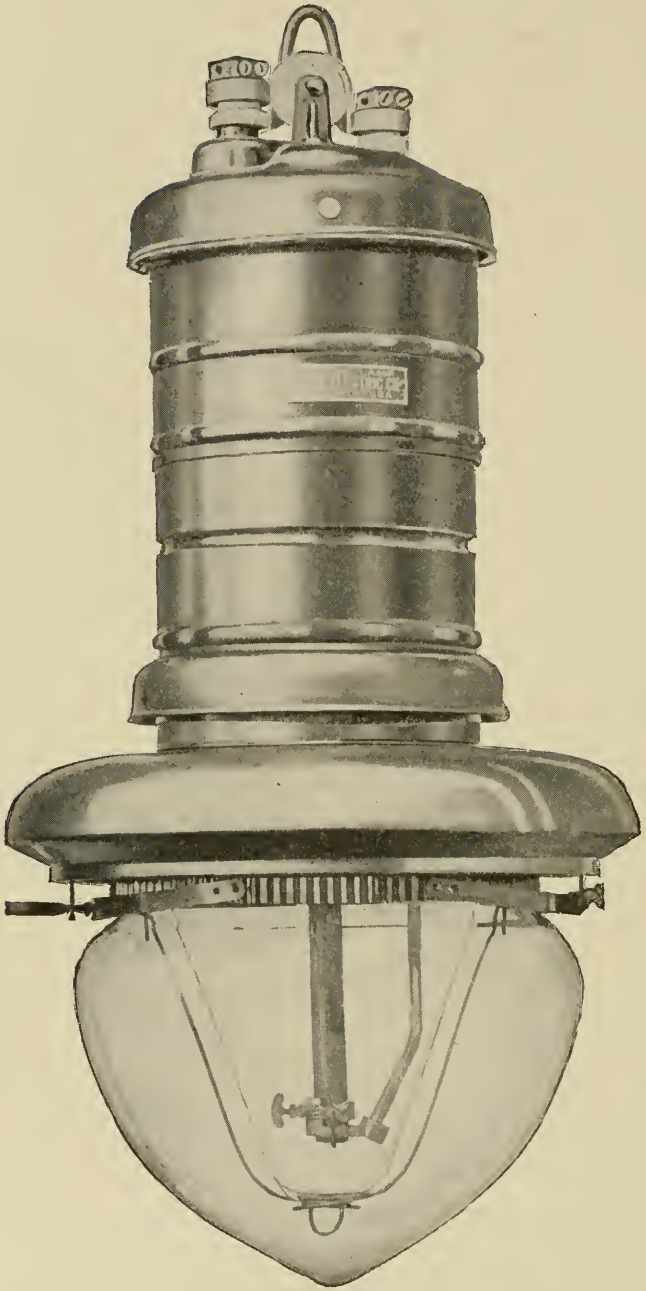
Cause 8. Field magnetism too powerful.

Remedy. Increase resistance of shunt-field circuit, by means of a shunt-field rheostat.

Cause 9. Machine compounds too much.

Remedy. Decrease resistance of series-field shunt. (See "Compound-Wound Dynamos", page 17, Part I.)

In commutating-pole generators it sometimes happens that the commutating poles themselves exert a compounding effect; especially is this true if the brushes are shifted slightly back of the proper neutral point.



GENERAL ELECTRIC MULTIPLE LONG-LIFE FLAME ARC LAMP

Courtesy of General Electric Company

ELECTRIC LIGHTING

HISTORY AND DEVELOPMENT

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the *voltaic arc*, and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great and the value of a study of this subject may be readily appreciated. Electricity may not always furnish the cheapest light, but its admirable qualities and its convenience of operation make it by far the most desirable.

CLASSIFICATION

The subject of electric lighting may be classified as follows:

(1) The type of lamps used.
(2) The methods of distributing power to the lamps.
(3) The use made of the light or its application.
(4) Photometry and lamp testing.

The types of lamps used may be subdivided into:

(1) Incandescent lamps: carbon and metallic filament.
(2) Special lamps: exhausted bulb without filament, such as the Cooper-Hewitt lamp and the Moore tube lamp.
(3) Arc lamps: ordinary carbon and flaming arc.

INCANDESCENT LAMPS

Historical. The incandescent lamp is by far the most common type of lamp used and the principle of its operation is as follows:

If a current of I amperes is sent through a conductor whose resistance is R ohms for a time t seconds, the conductor is heated, the heat generated being expressed in joules or watt-seconds thus:

$$\text{Heat generated} = I^2 R\, t$$

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, i. e., becomes incandescent and does not deteriorate too rapidly, we have an incandescent lamp. Carbon was the first successful material to be chosen for this conductor and for a long time all attempts to substitute another substance in place of carbon failed. Within the last few years metallic filament lamps have been introduced commercially with great success and the carbon incandescent lamp is now only used for special purposes such as in the case of very low candle-power units operated at commercial voltages.

Tungsten lamps are now used in the majority of cases and these and other types which have proved entirely or partially successful will be treated later. The present form of carbon incandescent lamp has, however, been much improved over the first forms and, owing to the historical importance of this lamp, the method of manufacture will be briefly considered.

CARBON FILAMENT LAMPS

ORDINARY TYPE

Method of Manufacture. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform gelatine-like mass. This material is then forced, "squirted", through steel dies into alcohol, the alcohol serving to harden the soft transparent threads, which are then dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the material becomes hard and stiff, assuming a permanent form; after cooling, the filaments are removed, measured, and inspected.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only conductor, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. The filament is fastened to the *leading-in* wires by means of the pasted joint. Finely powdered carbon is mixed with some adhesive compound such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of flashing, i. e., heating the filament to a high temperature in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament to accomplish the heating. The effects of flashing are as follows:

(1) The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will

be eliminated since the smaller sections, having the greater resistance, become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

(2) The surface is changed from a dull black and comparatively soft coating to a bright gray and much harder one, and which increases the life and efficiency of the filament.

Exhausting the Bulb. After flashing, the filament is sealed in the bulb and the air exhausted through the tube *A* in Fig. 1, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. Exhaustion is necessary for several reasons:

(1) To avoid oxidization of the filament.

(2) To reduce the heat conveyed to the globe.

(3) To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris.

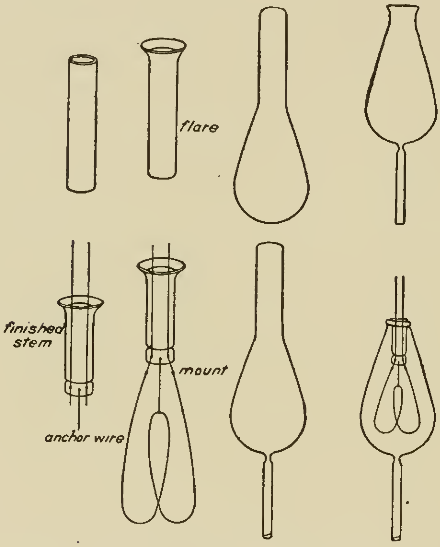


Fig. 1. Different Stages in the Manufacture of an Incandescent Lamp

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary, depending on the method of distribution of the power. For what is known as "parallel distribution", 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used; hence the filaments may be somewhat heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at 110 volts, or thereabouts.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112\times\frac{1}{2}=56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power, or simply watts per candle. *Watts economy* is sometimes used for *efficiency*.

The efficiency of a lamp depends on the temperature at which the filament is run. In the ordinary lamp this temperature is between 1280° and 1330° centigrade, and the curve in Fig. 2 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

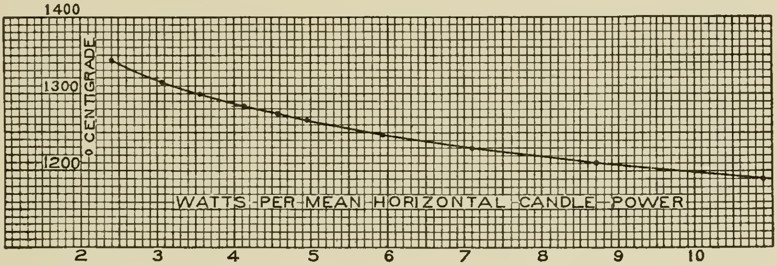


Fig. 2. Variations in Efficiency of an Incandescent Lamp with Temperature

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament; hence less energy is lost in heat radiation and the efficiency of the filament is increased.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat; hence the increase in efficiency shown in Fig. 2. Were it not for the rapid disintegration of the ordinary carbon filament at high temperature, an efficiency higher than 3.1 watts could be obtained. By a special treatment of the carbon filaments, the nature of the carbon is so changed that the filaments may be run at a higher temperature and the lamps may still have a life comparable to that of the 3.1-watt lamp. Lamps using these special carbon filaments are known as "gem metallized filament lamps", or merely as "gem lamps", and they will be described more fully later.

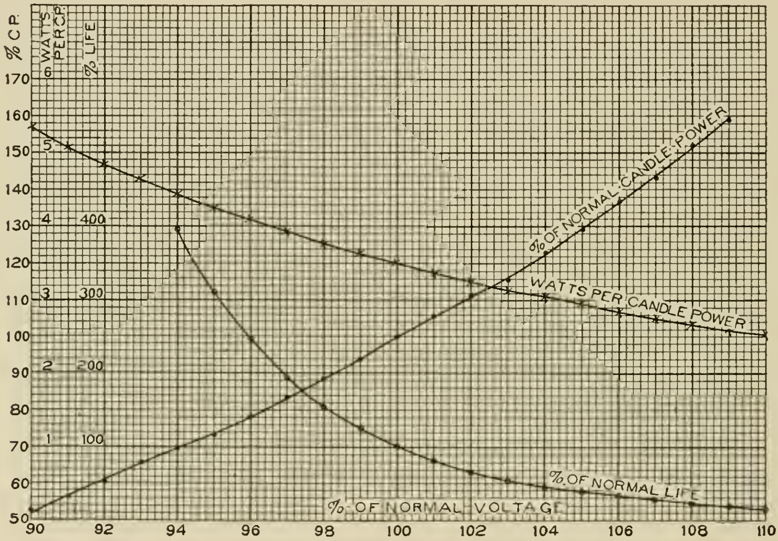


Fig. 3. Curves of Efficiency and Life of Carbon Filament Lamp

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such an extent that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80 per cent of the initial candle-power of carbon lamps is now taken as the point at which a lamp should be replaced and the normal life of a lamp is in the neighborhood of 800 hours. The curves in Fig. 3 show the relation between voltage, candle-power, efficiency, and life for the ordinary carbon lamp. These curves show that a 3 per cent increase of voltage on the lamp reduces the life by one-half, while an increase of 6 per cent causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1 watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the efficiency of the lamp to be installed.

Lamps should always be renewed at the end of their useful life—this point being termed the "smashing point"—as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced life, and it is not good practice to do this.

Fig. 4 shows the life curves of a series of carbon incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80 per cent of the initial candle-power.

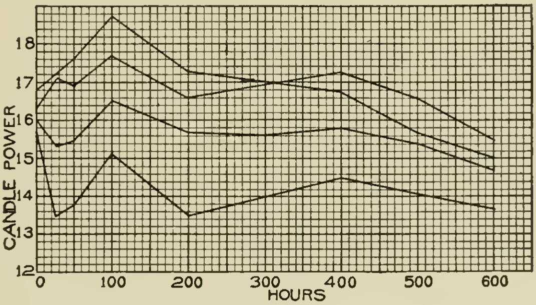


Fig. 4. Life Curves of Carbon Incandescent Lamps

GEM METALLIZED FILAMENT TYPE

Nature of Improvement. When the incandescent lamp was first well established commercially, the useful life of a unit, when operated at 3.1 watts per candle, was about 200 hours. The improvements in the process of manufacture have been continuous from that time until now and the useful life of a lamp, operated at that efficiency to-day, is in the neighborhood of 500 hours. Experiments in the treatment of the carbon filament have led to the introduction

TABLE I

Life and Efficiency Ratings of Gem Lamps at the Three Operating Efficiencies

Size of Lamp in Watts	HIGH EFFICIENCY		MEDIUM EFFICIENCY		LOW EFFICIENCY	
	W.P.C.	Average Total Life in Hours	W.P.C.	Average Total Life in Hours	W.P.C.	Average Total Life in Hours
40	2.56	600	2.71	900	2.89	1300
50	2.50	700	2.65	1000	2.81	1500
60	2.50	700	2.65	1000	2.81	1500
80	2.46	700	2.60	1000	2.78	1500
100	2.46	650	2.60	950	2.78	1400

of the gem metallized filament lamp. This lamp should not be confused with the metallic filament lamps, to be described later, because the material used is carbon, not a metal. As a result of special treatment the carbon filament assumes many of the characteristics of a metallic conductor, hence the term "metallized filament". The word "graphitized" has been proposed in place of metallized.

Preparation of Filament. When a filament, as treated in the ordinary manner, is run at a high temperature in a lamp, there is no improvement of the filament, but it was discovered that if the treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3000 to 3700 degrees centigrade—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and a higher efficiency, and still maintain a life comparable to that of a 3.1-watt lamp. This special heating of the filament, which is applied to the base filament before it is flashed, as well as to the treated filament, causes the cold resistance of the carbon to be very materially decreased and the filament, as used in the lamp, has a positive temperature coefficient—rise in resistance with rise in temperature—a desirable feature from the standpoint of voltage regulation of the circuit from which the lamps are operated. The high temperature also results in the driving off of considerable of the material which, in the ordinary lamp, causes the globe to blacken after the lamp has been in use for some time. The blackening of the bulb is responsible to a considerable degree for the decrease in candle-power of the incandescent lamp. The metallized filament lamp is operated at an efficiency of 2.5 watts per candle with a useful life of about 700 hours. The change in candle-power with the change in voltage is less than in the ordinary lamp on account of the positive temperature coefficient of the filament. These lamps are not manufactured for very low candle-powers, owing to the difficulty of treating very slender filaments, but they are made in sizes consuming from 40 to 250 watts. Table I gives some useful information in connection with metallized filament lamps. The filaments are made in a variety of shapes and the distribution curves are usually modified in practice by the use of shades and reflectors. The general appearance of the lamp does not differ from that of the ordinary carbon lamp.

METALLIC FILAMENT LAMPS

TANTALUM TYPE

Nature of Filament. The first of the metallic filament lamps to be introduced to any considerable extent commercially was the tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and a high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon filament lamp. On account of the comparatively low specific resistance of this material the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 5, 6, and 7 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per candle-power, with a life comparable to that of the ordinary lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used

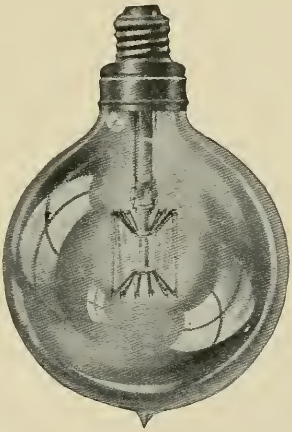


Fig. 5. Round Bulb Tantalum Lamp

in the first of the tantalum lamps. It should be noted that the life of this type of lamp on alternating-current circuits is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits.

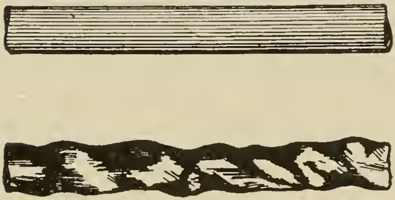


Fig. 6. Tantalum Filament Before and After One-Thousand Hours' Use

TUNGSTEN VACUUM TYPE

Early Methods of Preparing Filament. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point. An indirect method was originally employed in forming filaments for incandescent lamps and there were several of these methods in use. In one method a fine carbon filament was flashed in an atmosphere of tungsten oxychloride mixed with just the proper proportion of hydrogen, in which case the filament gradually changed to one of tunsgten. A second method consisted of the use of powdered tungsten and some binding material, sometimes organic and in other cases metallic. The powdered tungsten was mixed with the binding material, the paste squirted into filaments, and the binding material was then expelled, usually by the aid of heat. Another method of manu-

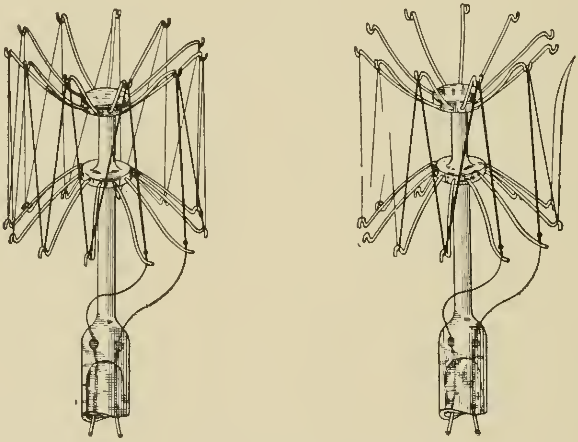


Fig. 7. Mounted Tantalum Filament Showing Appearance after Considerable Use and after Filament Has Disintegrated

facture consisted of securing tungsten in colloidal form, squirting it into filaments, and then changing them to the metallic form by passing electric current through them.

Difficulties in Providing Required Durability. Tungsten lamps, as formed by any of the above or similar processes, are extremely fragile, especially when cold, and the tungsten lamps in their early forms required very careful packing for shipment; were easily broken in ordinary service; could not be used satisfactorily where there was appreciable vibration; and there was a considerable reduction in candle-power with use, due to the blackening of the bulb. The first commercial tungsten lamps were produced in 1907, or thereabouts, and the development of the lamp has been continuous since that time. An efficiency of about 1.25 watts per candle-power was early realized for lamps of 100 watts rating or higher, and lamps consuming 40 and 60 watts were early available. In 1911 a process was developed for preparing tungsten in ductile form and wiredrawn filaments were made. These filaments proved to be much stronger than the filaments prepared by other processes but still further development has made the present wiredrawn filaments as much more rugged than the first drawn filaments as these were stronger than the filaments made by other processes.

Wiredrawn Filaments. In the first stages of development, wiredrawn filaments were prepared only with the very greatest difficulty but the wire can now be produced in any desired length and very uniform in cross section. The material for the filaments comes to the filament factory in the form of a concentrated tungsten ore from which tungstic oxide is obtained. This oxide is reduced by a special process requiring the agency of an electric furnace to produce tungsten metal in a powdered form. This tungsten metal is compressed into ingots about 6 inches long by one-fourth of an inch square and again heat-treated in an electric furnace, the effect of which treatment is to strengthen the ingot and make the material a good conductor of electricity. The material is then subjected to a temperature near the melting point in an atmosphere of hydrogen and the result of this treatment is to weld the tungsten particles firmly together. The ingot is then heated and swaged and the process repeated until it forms a rod about .03 inch in diameter and 30 feet long. This rod is hot drawn through special diamond dies and

TABLE II

Data on Standard Mazda Lamps

Voltage Range	WATTS		EFFICIENCY			CANDLE-POWER	
	Rated	Actual	Rating	W.P.C.	Lumens per Watt	Mean Horiz'l	Mean Spherical
100 to 130	15	15.0	High	1.30	7.54	11.54	9.0
		14.6	Medium	1.35	7.26	10.80	8.4
		14.2	Low	1.40	7.00	10.15	7.9
	20	20.0	High	1.25	7.84	16.00	12.5
		19.5	Medium	1.30	7.54	15.04	11.7
		19.0	Low	1.34	7.31	14.20	11.1
	25	25.0	High	1.17	8.38	21.38	16.7
		24.25	Medium	1.22	8.03	19.96	15.6
		23.6	Low	1.27	7.72	18.55	14.5
	40	40.0	High	1.17	8.38	34.20	26.7
		38.9	Medium	1.22	8.03	32.00	25.0
		37.8	Low	1.27	7.72	30.00	23.4
	60	60.0	High	1.16	8.45	51.70	40.3
		58.3	Medium	1.21	8.10	48.40	37.7
		56.6	Low	1.26	7.78	45.00	35.1
	100	100.0	High	1.13	8.68	88.50	69.0
		97.2	Medium	1.18	8.30	82.40	64.2
		94.2	Low	1.23	7.97	77.10	60.1
	150	150.0	High	1.12	8.75	134.00	104.5
		146.0	Medium	1.17	8.38	125.00	97.5
		142.0	Low	1.22	8.03	116.00	90.5
	250	250.0	High	1.00	9.80	250.00	195.0
		244.0	Medium	1.04	9.42	234.00	182.5
		238.0	Low	1.08	9.07	220.50	172.0
200 to 260	25	25.0	Single	1.40	7.05	17.90	14.1
	40	40.0	Single	1.31	7.58	30.50	24.1
	60	60.0	Single	1.31	7.58	45.80	36.2
	100	100.0	Single	1.31	7.58	76.40	59.8
	150	150.0	Single	1.31	7.58	114.50	90.4
	250	250.0	Single	1.31	7.58	190.80	150.8

finally reduced to the desired size, the final drawings being made at lower temperatures or cold. Graphite is used as a lubricant during the process of drawing. The filament of a 10-watt 110-volt lamp is about .00075 inch in diameter, a remarkably fine wire. The balance of the manufacture of the tungsten lamp is not unlike that of the carbon incandescent lamp already described.

Improvements over Carbon Type. The modern tungsten lamp, in addition to the increased mechanical strength, shows improvements such as: the use of a chemical in the bulb to better the candle-power maintenance; a decrease in the size of the glass bulb and a complete standardization of bulb sizes; and the production of special forms of the filament, such as the helical form.

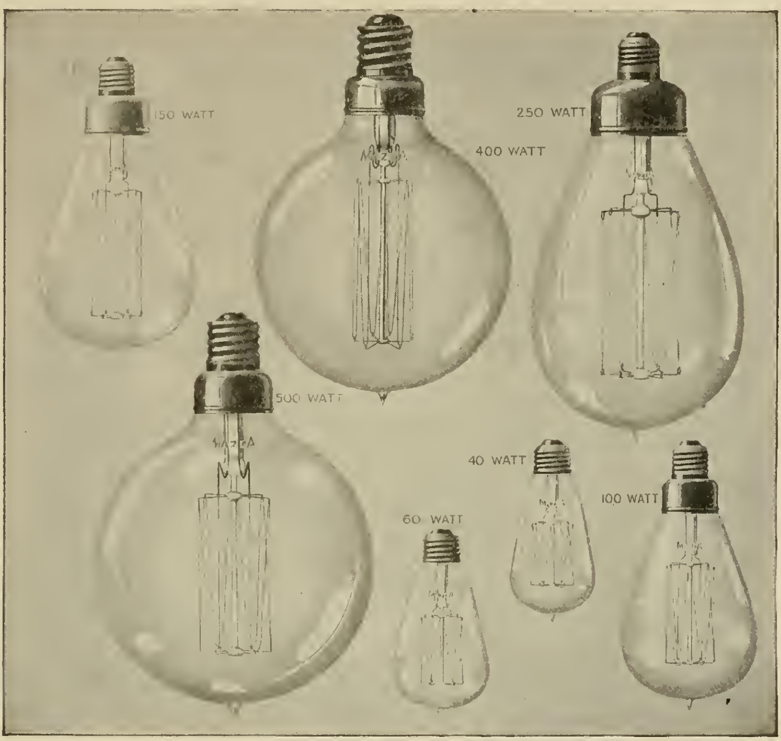


Fig. 8. Collection of Various Sizes of Mazda Lamps
Courtesy of National Electric Lamp Association

Table II gives useful data covering the regular Mazda lamp and Fig. 8 shows the appearance of these units.

In addition to lamps for 110- and 220-volt service the tungsten lamp forms a very desirable type of unit for series systems of street lighting. Still another field is that of low-voltage lamps for train lighting, sign lighting, automobiles, etc., and the tungsten filament is well adapted to miniature lamps which operate at low voltages.

In addition to the higher efficiency the tungsten lamp has still another advantage over the older carbon lamps in that the variation in candle-power with a change in voltage is not as great; hence poor voltage regulation of the distribution system is not so noticeable with the tungsten lamps. The curves in Fig. 9 show the relative behavior of the different types of filaments in this respect and indicate decidedly less change in candle-power for a given change in voltage for the tungsten lamp. Finally the light given by the tungsten filament, as used in the tungsten lamp, is whiter than that of any of the other filaments and hence is more desirable for most classes of illumination.

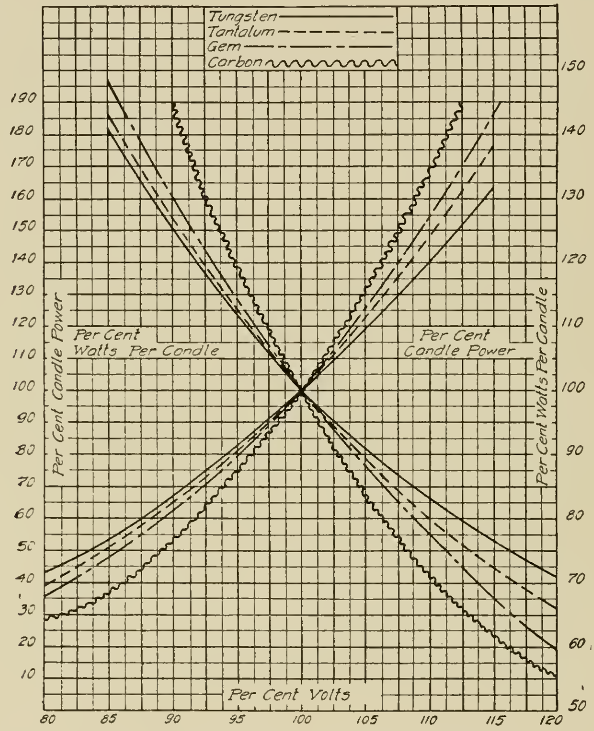


Fig. 9. Curve Showing Variation of Candle-Power and Watts per Candle Due to Change of Voltage

NITROGEN-FILLED TYPE

Characteristics and Efficiency. This lamp, Fig. 10, is the final word, at the present time, in the improvement of filament types of incandescent lamps and it is a recent improvement upon the tungsten lamp as ordinarily manufactured. One of the results of the continuous research, which has been carried on in connection with incandescent lamps, has been to show that if, instead of containing a high vacuum, the bulb of the tungsten lamp is filled with the inert gas nitrogen, at practically atmospheric pressure, and the filament then run at a very much higher temperature than had ordinarily been used with the vacuum type of lamp, the efficiency of the lamp could be improved and the life of the unit kept in the neighborhood of 1000 hours, the normal life rating of the regular incandescent units. So far, such lamps have been manufactured in very large units for the standard lighting circuits, rated at 750 and 1000 watts and giving an efficiency

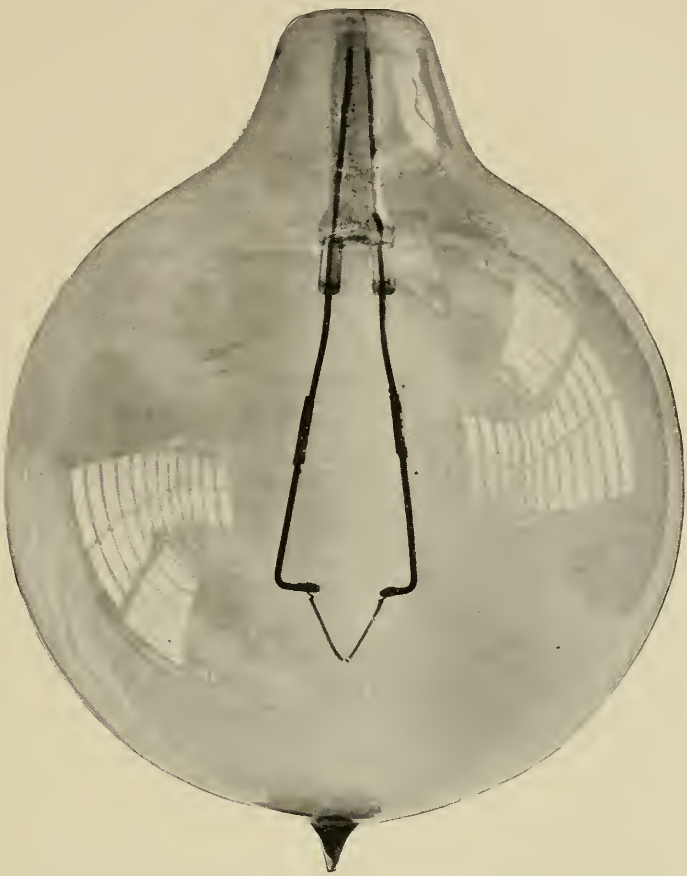


Fig. 10. Unmounted Nitrogen-Filled Lamp Showing Short Helical Filament

TABLE III

Tentative Data covering Nitrogen-Filled Mazda Lamps for Street Lighting Service on Series Circuits

(Rated Life—1350 hours)

CANDLE-POWER	AMPERES	WATTS PER CANDLE-POWER
80	6.6	.71
100	6.6	.70
250	6.6	.68
400	6.6	.66
600	6.6	.66
80	7.5	.71
250	7.5	.68
400	20.0	.5
600	20.0	.5
1000	20.0	.5

of .65 to .60 watts per candle-power; in sizes from 80 to 1000 candle-power for series lighting circuits and operating at efficiencies of from .71 to .5 watts per candle-power; and special lamps giving several thousand candle-power and operating at about .5 watts per candle-power.

It is expected that the development of this type of lamp will continue. At the present time lamps are only made with filaments of comparatively large cross section or filaments in rather tightly coiled helixes, Fig. 10; otherwise the appearance of the lamp is not different from that of the usual unit as manufactured for high candle-powers.

Table III gives tentative data on nitrogen-filled street-lighting units for series circuits.

The Just lamp, the Z lamp, the Osram lamp, the Zircon-Wolfram lamp, the Osmin lamp, etc., were all tungsten lamps, the filaments being prepared by some of the general methods already described, or modifications of them.

MISCELLANEOUS TYPES

Other Metallic Filament Lamps. Table IV gives the melting points of several metals which are highly refractory and those already mentioned are not the only ones which have been successfully used in incandescent lamps. Titanium, zirconium, iridium, etc., have

TABLE IV

Melting Point of Some Metals

Metal	Approximate Melting Point in Degrees Centigrade
Tungsten	3080–3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Carbon (not a metal)	3000

been successfully employed, but tungsten lamps are the only ones which are used to any extent in the United States.

Nernst Lamp. The Nernst lamp is still another form of incandescent lamp, one type of which is shown in Fig. 11. The lamp is no longer manufactured but it was used quite extensively at one time and a brief description is given here.

Glower. This lamp used for the incandescent material certain oxides of the rare earths, the oxides being mixed in the form of a paste, then squirted through a die into a string which was subjected to a roasting process forming the filament or *glower* material of the lamp. The more recent glowers were made hollow instead of solid. The glowers were cut to the desired length and platinum terminals attached. The attachment of these terminals to the glowers was an important process in the manufacture of the lamp. The glowers were heated to incandescence in open air, a vacuum not being required.

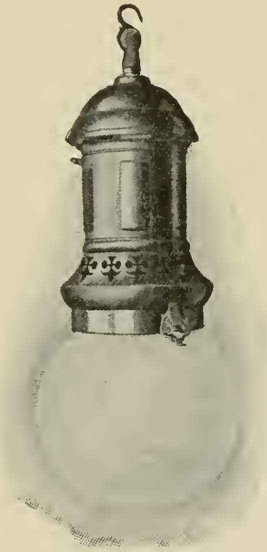


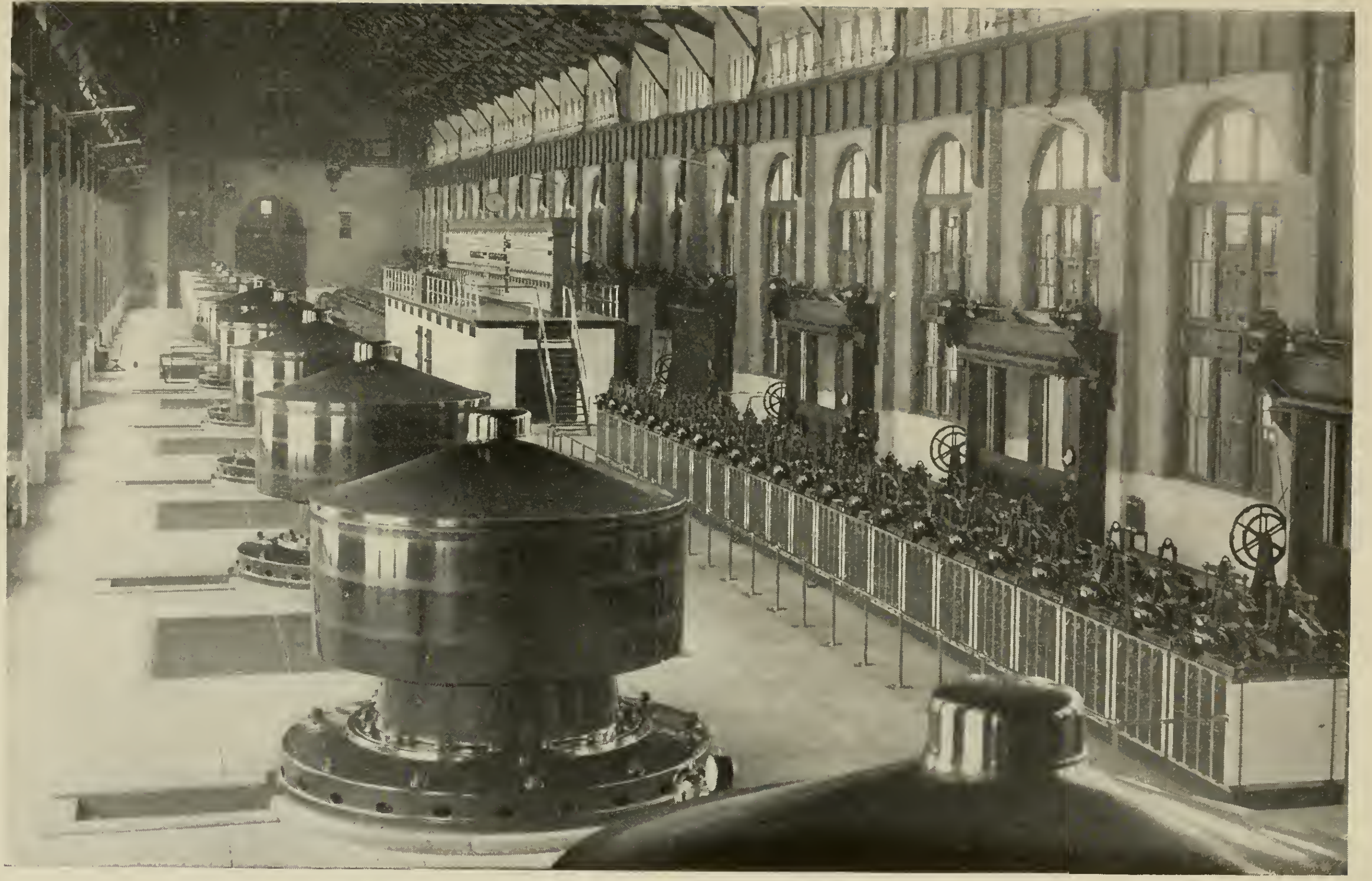
Fig. 11. Westinghouse Nernst Multiple-Glower Lamp

Heater. As the glower is a nonconductor when cold, some form of heater was necessary to bring it up to a temperature at which it would conduct. One form of heater consisted of a porcelain tube placed just above the glower, about which a fine platinum wire was wound; the wire was coated with a cement. Two or more of these tubes were mounted directly over the glower, or glowers, and served as a reflector as well as a heater.

The heating device was connected across the circuit when the lamp was first turned on, and it had to be cut out of circuit after the glowers became conductors in order to save the energy consumed by the heater and to prolong the life of the heater. The automatic cut-out was operated by means of an electromagnet so arranged that current flowed through this magnet as soon as the glower became a conductor, and contacts in the heater circuit were opened by this magnet. The contacts in the heater circuit were kept normally closed, usually by the force of gravity.

Ballast. The conductivity of the glower increased with the increase of temperature—the material has a negative temperature coefficient; hence, if it were used on a constant potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current from increasing beyond the desired value, a ballast resistance was used in series with the glower. As is well known, the resistance of iron wire increases rapidly with increase in temperature, and the resistance of a fine pure iron wire was so adjusted that the resistance of the combined circuit of the glower and the ballast became constant at the desired temperature of the glower. The iron wire had to be protected from the air to prevent oxidization and too rapid temperature changes and, for this reason, it was mounted in a glass bulb filled with hydrogen. Hydrogen was selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

Advantages Claimed. All of the parts enumerated, namely, glower, heater, cut-out, and ballast, were mounted in a suitable manner; the smaller lamps with but one glower were arranged to fit in an incandescent lamp socket, while the larger types were constructed with as many as four glowers and were arranged to be supported in special fixtures, like small arc lamps. All parts were mechanically arranged so that renewals might easily be made when necessary and it was not possible to insert a part belonging to one type of lamp into a lamp of a different type.



ELEVEN 4000-K.W. 2200-VOLT GENERATORS, POWER HOUSE NO. 2, NIAGARA FALLS POWER COMPANY

Courtesy of General Electric Company

The advantages claimed for the Nernst lamp were: high efficiency; a good color of light; a good distribution of light without the use of reflectors; a long life with low cost of maintenance; and a complete series of units, thus allowing its adaption to practically all classes of illumination.

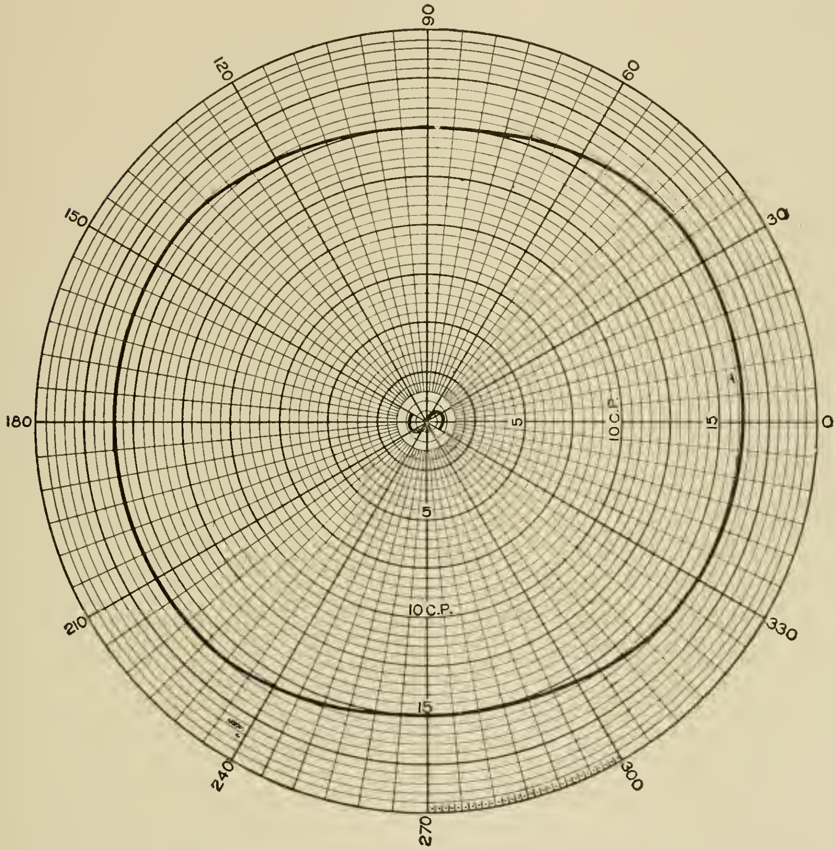


Fig. 12. Horizontal Distribution Curve for Single-Loop Carbon Filament

Nernst lamps were made for 110- and 220-volt service and in sizes from 66 to 528 watts, giving a mean candle-power below the horizontal of from 50 to 500 and an efficiency of from 1.38 to 1.09 watts per mean hemispherical candle-power.

DISTRIBUTION CURVES

Nature and Value. By a distribution curve for any type of lamp is meant a curve showing the value of the light given by the lamp in different directions. Usually these curves take the form of vertical distribution curves in which the light given in the different directions throughout 360 degrees in a vertical plane are given and a horizontal distribution curve in which the light given in different directions throughout 360 degrees in a horizontal plane are given. The mean of the values of the candle-power in a horizontal plane gives the mean horizontal candle-power, while a mean of the values in the vertical plane gives the mean vertical candle-power of the

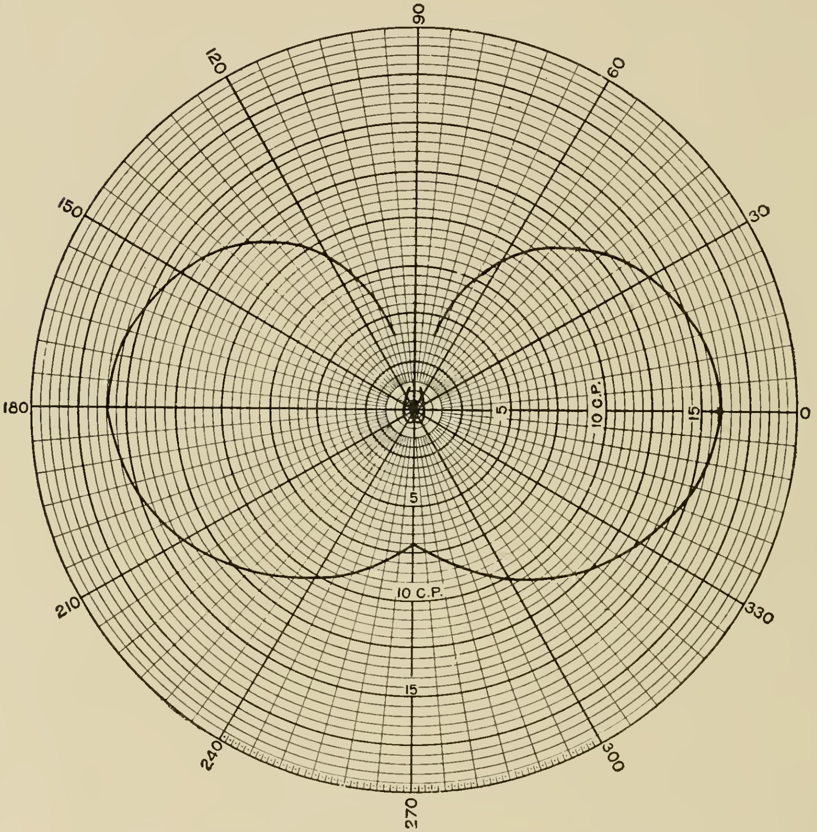


Fig. 13. Vertical Distribution Curve for Single-Loop Carbon Filament

light source. In the absence of more specific statements the candle-power of a lamp is taken to be the mean *horizontal* candle-power.

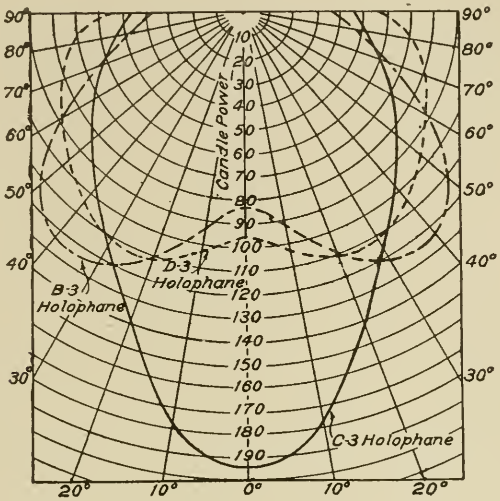


Fig. 14. C. P. Distribution Curves of 100-Watt G. E. Tungsten Lamps with B-3, C-3, and D-3 Holophane Reflectors

The use of shades and reflectors greatly modifies the form of the distribution curves of lamps, the exact nature of the modification depending upon the design of the shade or the reflector. Since

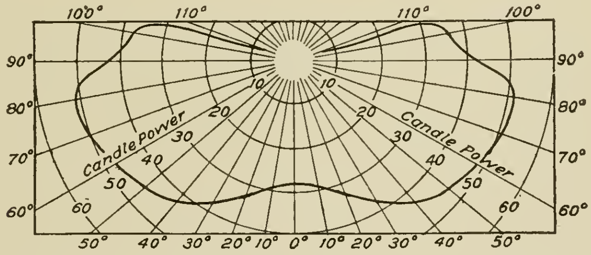


Fig. 15. C. P. Distribution Curve for 40-C. P., G. E. Tungsten Series Lamp with Radial Wave Reflector

lamps are almost always used with some type of shade or reflector, the distribution curves of the bare lamps have their greatest usefulness for comparative purposes. The distribution curves of the lamps with the reflectors are of direct use in calculations of illumination. Figs. 12 to 19 inclusive are typical of the distribution curves of incandescent lamp units.

Mean Spherical Candle=Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used

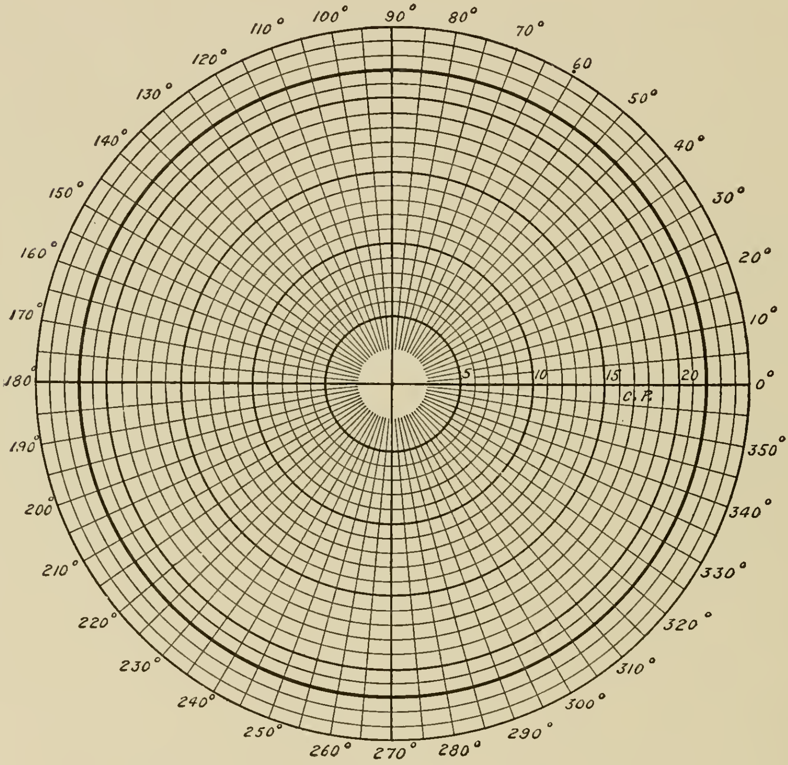


Fig. 16. Horizontal Distribution Curve of a Mazda Lamp

instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under "Photometry". The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane. The *spherical reduction factor* for the ordinary tungsten lamp is from .78 to .79.

SPECIAL VAPOR LAMPS

STANDARD MERCURY VAPOR LAMP

Operating Principles. The mercury vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and it is being used to a considerable extent for industrial illumination.

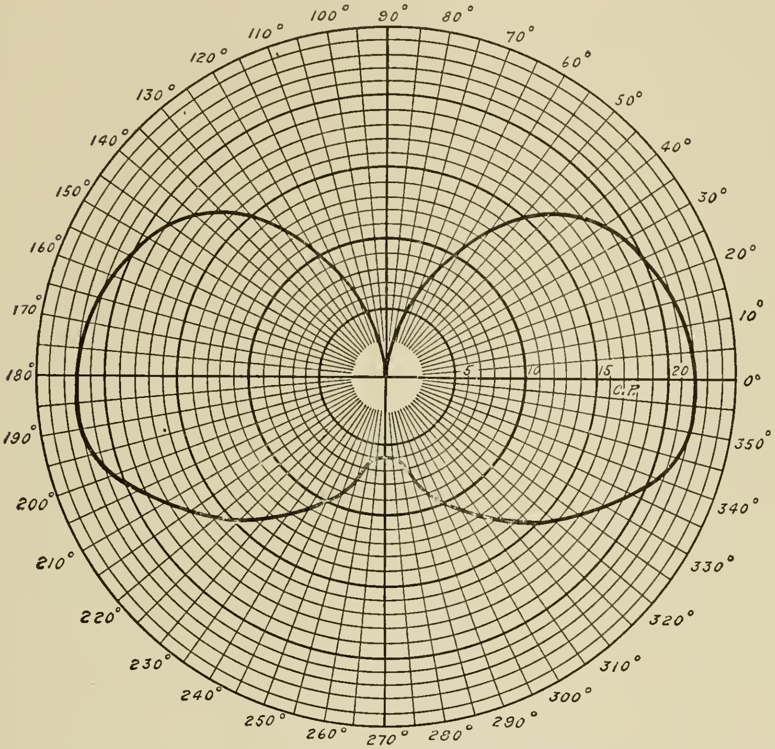


Fig. 17. Vertical Distribution Curve of a Mazda Lamp

In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup and the connections between the lamp terminals and the electrodes are platinum where this connection passes through the glass. Fig. 18 gives the general appearance of a standard lamp having the following specifications:

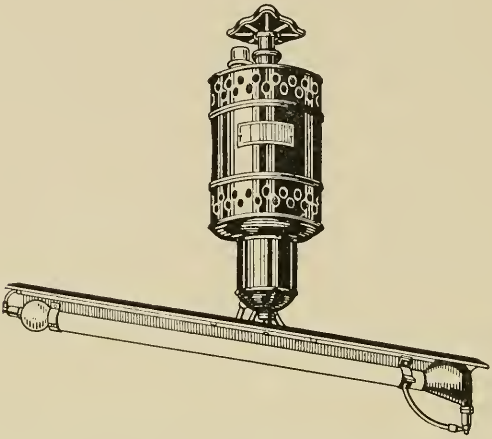


Fig. 18. Cooper-Hewitt "Type H" Mercury Vapor Lamp
Courtesy of Cooper-Hewitt Electric Company

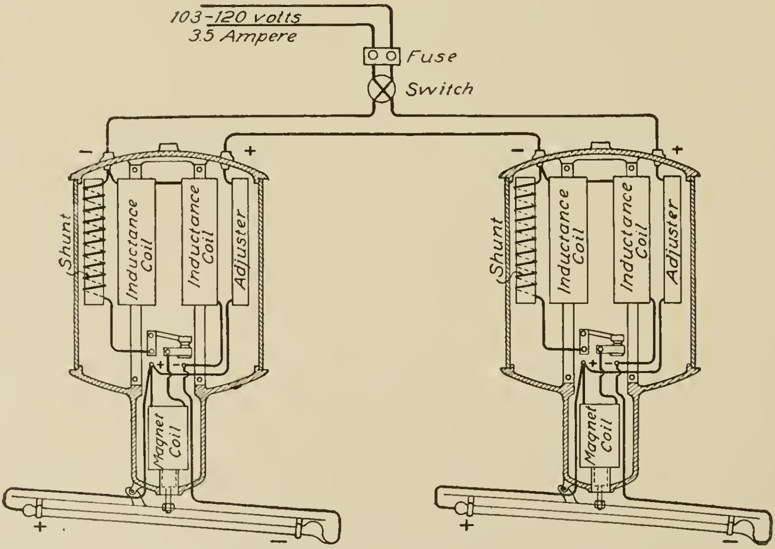


Fig. 19. Wiring Diagram for Two "Type H" Cooper-Hewitt Automatic Lamps in Series

Total watts (110 volts, 3.5 amperes) = 385
Candle-power (M. H. with reflector) = 700
Watts per candle = 0.55
Length of tube, total = 55 inches
Length of light-giving section = 45 inches
Diameter of tube = 1 inch
Height from lowest point of lamp to ceiling plate = 22 inches
For 220-volt service two lamps are connected in series.

Forming Mercury Vapor. The mercury vapor, at the start, may be formed in two ways: First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and the mercury is vaporized when the stream breaks; and second, by means of a high inductance and a quick-break switch, a very high voltage, sufficient to pass a current from one electrode to the other through the vacuum, is induced and the conducting vapor is

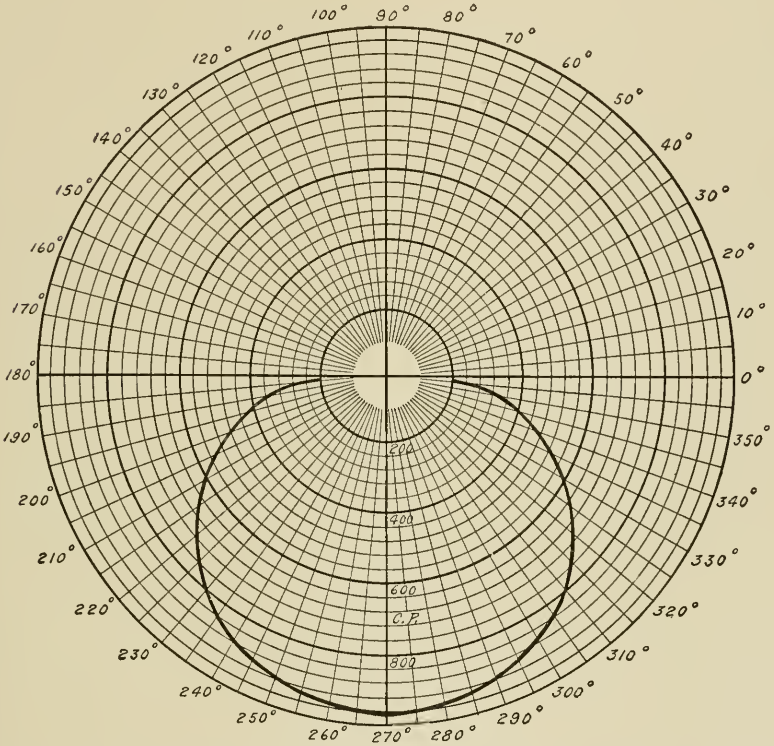


Fig. 20. Distribution Curve of a 21-Inch 3.3-Ampere Direct-Current Mercury Vapor Lamp

formed. The tilting method of starting is preferred and this tilting is brought about automatically in the more recent types of lamp. Fig. 19 shows the connections for starting automatically two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

Applications. The mercury vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes as there is an entire absence of red rays, in fact, the light is practically monochromatic. The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color, the application of this lamp is limited to the lighting of shops, offices, and drafting rooms, or to display windows where the goods shown will not be changed in appearance by the color of the light. It is used to a considerable extent in photographic work on account of the chemical properties of the light. Special reactances must be provided for a mercury arc lamp operating on single-phase alternating-current circuits. These alternating-current lamps have practically the same efficiency as the direct-current lamps.

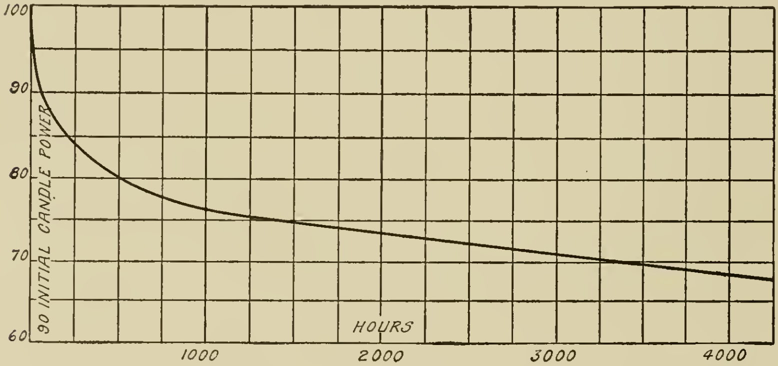


Fig. 21. Candle-Power Performance of Two 21-Inch, 55-Volt 3.3-Ampere Mercury Vapor Lamps

The distribution of light about a plane taken at right angles to the tube of a Cooper-Hewitt lamp is shown in Fig. 20. The change in candle-power with use is illustrated in Fig. 21.

QUARTZ MERCURY VAPOR LAMP

Comparison with Ordinary Mercury Lamp. *Increase in Voltage and Temperature.* Since in the mercury vapor lamp the arc at the electrode gives practically no light but consumes some energy and the bulk of the light is given by the mercury vapor column, the efficiency of the mercury vapor tube as a light giving source is improved by using very long tubes, as in the standard lamp; or the performance may be improved by using a higher voltage per unit length of the tube than is ordinarily employed, provided a tube can be made to withstand the higher temperatures reached with this higher voltage per unit length. The vapor pressure is low in the regular glass tube, seldom over one-eighth inch of mercury pressure, but if the tubes are made of quartz, which is capable of standing a much higher temperature than ordinary glass, the drop in potential per inch of tube length can be increased to 30 or more times that allowable with glass tubes.

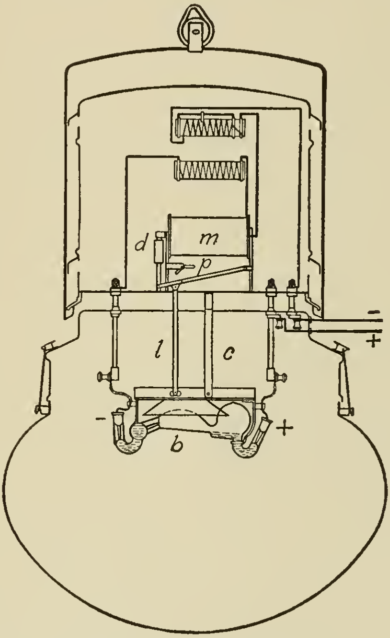


Fig. 22. Diagram of 110-Volt 3.8-Ampere Cooper-Hewitt Quartz Lamp

White Color of Light. When operated in this manner the mercury vapor actually becomes incandescent and the character of the light given by the lamp is changed, red and orange rays being added to the yellow, blue, green; and violet of the ordinary mercury vapor lamp. The pioneer work on this type of lamp was done in Germany but it has since been taken up in the United States and the lamp has been developed into a commercial form.

Construction and Operation. The light-giving element of the commercial lamp is a short tube of quartz containing mercury vapor. The necessary mechanism for starting and controlling the lamp is placed in a hood above the quartz tube and the tube itself is sur-

TABLE V

Data on Quartz Tube Lamps (Cooper-Hewitt)

Volts, Nominal	Current, Average	Candle-Power Mean Hemispherical With Clear Glass Globe	Watts per Mean Hemispherical Candle-Power
110	3.8	1000	0.42
220	3.3	2400	0.30
550	2.0	3500	0.31

rounded by a glass globe, partly for the purpose of cutting off the ultra-violet light given by the mercury vapor and not screened off by the quartz tube. The details of a Cooper-Hewitt quartz lamp are illustrated in Fig. 22 and the general appearance of one of these lamps is shown in Fig. 23. Referring to Fig. 22, which illustrates the mechanism of a 110-volt 3.8-ampere direct-current lamp: *b* is the quartz tube or burner placed in a suitable holder which is pivoted in a support c and attached to the lever *l*; *l* is linked to the movable iron armature *m*; *d* is a dashpot; *p* is a small permanent magnet installed for the purpose of locking the mechanism and preventing its operation, if the lamp should be connected in to the circuit with a wrong polarity. Closing the lamp switch automatically tips the quartz tube and starts the lamp in operation. Table V gives some operating data for the Cooper-Hewitt quartz lamp.

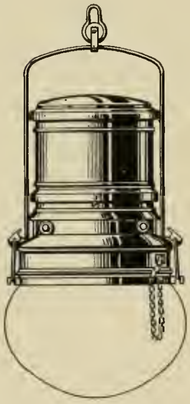


Fig. 23. Standard Cooper-Hewitt Quartz Lamp

TUBE LIGHTING

Moore Tube Light. *Use of Geissler Tube Principle.* The Moore light makes use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount of consistent research on the part of the inventor and it has now been brought to such a stage that several installations have been made. The system, while probably not destined to have any extended commercial use, has many interesting features.

Method of Installation. In the normal method of installation, a glass tube 1¾ inches in diameter is made up by connecting standard lengths of glass tubing together until the total desired length is reached and this continuous tube, which forms the source of light when in operation, is mounted in the desired position with respect to the plane of illumination. In many cases the tube forms a large rectangle mounted just beneath the ceiling of the room to be lighted. The tube may be of any reasonable length, actual values running from 40 to 220 feet. In order to provide an electrical discharge through this tube it is customary to lead both ends of the tube to the high tension terminals of a transformer, Fig. 24, the low tension side of which may be connected to the alternating-current lighting mains. This transformer is constructed so that the high tension terminals are not exposed and the current is led into the tube by means of platinum wires attached to carbon electrodes. The electrodes are about 8 inches in length. The ends of the tube and the high tension terminals are enclosed in a steel casing so as effectually to prevent anything from coming in contact with the high potential of the system. As stated, the low tension side of the transformer is connected to the usual 60-cycle lighting mains. If direct current is used for distribution, a motor-generator set for furnishing alternating current to the primary of the transformer is required. Any frequency from 60 cycles up is suitable for the operation of these tubes. At lower frequencies there is some appreciable variation of the light emitted.

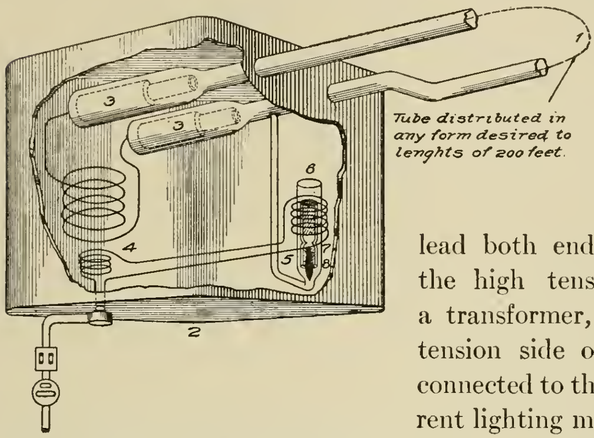

1
3
3
Tube distributed in any form desired to lenghts of 200 feet.
8
4
5
7
6
2

Fig. 24. Diagram Showing Essential Features of Moore Light. *1*-Lighting Tube; *2*-Transformer Case; *3*-Lamp Terminals; *4*-Transformer; *5*-,*6*-,*7*-, *8*-Regulators

Color of Light. The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted to it when

TABLE VI

Data on the Moore Tube Light

Length of Tube	Transformer Capacity	Power Factor of Circuit	Voltage at Lamp Terminals
40–70 ft.	2 kw.	65–84%	3146 for 40-ft. tube, at 12 hefners per ft.
80–125 "	2.75 "		
130–180 "	3.5 "		
190–220 "	4.5 "		12,441 for 220-ft. tube, at 12 hefners per ft.

the tube is in operation. The tube gives the highest efficiency when nitrogen is employed and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube and carbon dioxide is employed when a white light is desired.

Advantages Claimed. Table VI gives general data on the Moore tube light. The advantages claimed for this light are: high efficiency, good color, and low intrinsic brilliancy.

Pressure in tube, about $\frac{1}{10}$ mm. of mercury.
Watts per hefner, 3.2 for 20-foot tube including transformer.
Watts per hefner, 1.4 for 180-foot tube including transformer.
Hefner per foot, normal, 12.
Note that one hefner equals 0.88 candle-power.

Neon Tube Light. *Characteristics and Advantages of Method.* Neon, a rare gas of which the atmosphere contains about one part in 66,000, can be obtained as a by-product of the manufacture of oxygen from the air and it may be used in connection with tube lighting in a manner similar to the way in which nitrogen is used in the Moore lamp. When used in this manner it must be in a very pure state. Lamps have been manufactured for the use of neon, with the following general characteristics:

Tubes 6 meters long have a life comparable to that of incandescent lamp units, namely 1000 hours, or more.

The necessary potential is about one-third that required for a similar Moore tube—about 800 volts for a tube 6 meters long.

The neon tube gives about 200 candle-power per meter of length as against about 60 candle-power for a nitrogen tube.

An efficiency of 0.5 watts per candle is claimed for the neon tube.

Color of Light. The color of the light, unmodified, is too red for ordinary illumination. To improve this, correcting tubes containing mercury have been added to some lamps and, by the use of such correcting tubes, the color has been greatly improved but the efficiency of the unit is reduced so that about 0.8 watt per candlepower is required for their operation.

Small tubes for display lighting have been manufactured but it is not at all likely that neon tubes, in their present state of development, will have any great commercial application, even though they have some very desirable characteristics.

CARBON ARC LAMPS

ORDINARY OPEN AND ENCLOSED ARC TYPES

Principles of the Electric Arc. Suppose two carbon rods are connected in an electric circuit and the circuit is closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2000 cells and produced an arc between charcoal points 4 inches apart.

Nature of Arc. As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for a large portion of arc lamps, it will be well to study the nature of the arc. Fig. 25 shows the general appearance of an arc between two carbon electrodes when maintained by direct-current.

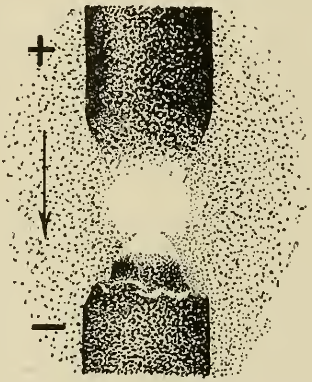


Fig. 25. Electric Arc Between Carbon Terminals

Action of Current on Carbons. Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the "crater" of the arc. This crater has a temperature of from 3000 to 3500 degrees centigrade, the temperature at which the carbon vaporizes, and it gives from 80 to 85 per cent of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5 per cent of the light emitted when pure carbon electrodes are used.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

Preparation of Carbons. Carbons are either molded or forced from a product known as "petroleum coke" or from similar materials, such as lampblack. The material is thoroughly dried by heating to a high temperature; then it is ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground, it is ready for molding. The powder is put in steel molds and heated until it takes the form of a paste, when the necessary pressure is applied to the molds. For the forced carbons, the powder is formed into cylinders which are placed in machines that force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether molded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross section and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a

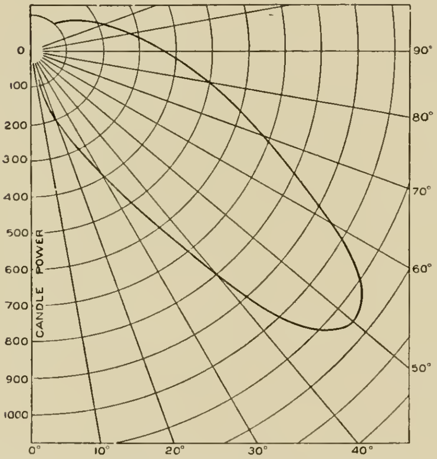


Fig. 26. Distribution Curve for D. C. Arc Lamp in Vertical Plane

different material seems to change the quality of light and, being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for molded forms for the purpose of increasing the conductivity and, by protecting the carbon near the arc, prolonging the life.

Distribution Curve. The light distribution curve of a direct-current arc, taken in a vertical plane, is shown in Fig. 26. Here it is seen that the maximum amount of light is given off at an angle of about 50 degrees from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

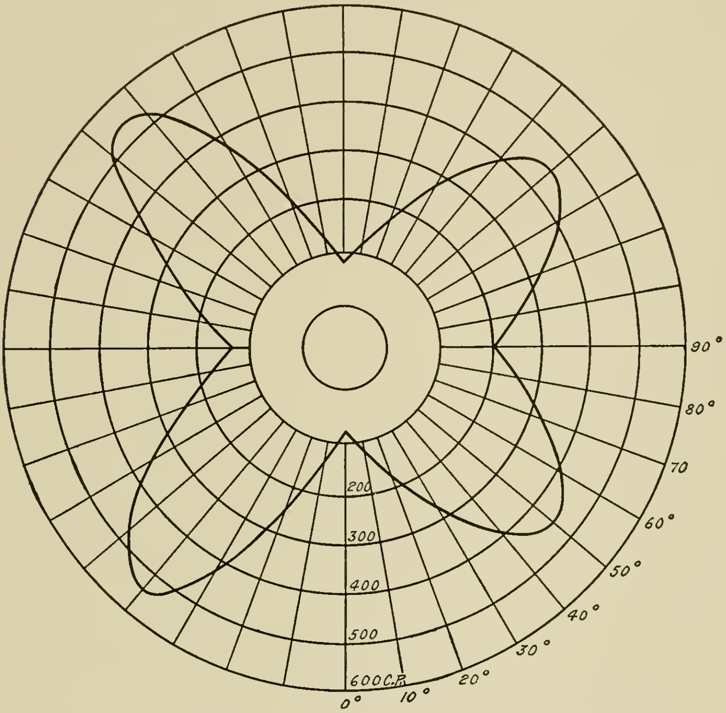


Fig. 27. Distribution Curve for A. C. Arc Lamp in Vertical Plane

If alternating current is used, the upper carbon becomes positive and negative alternately and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an alternating-current arc is shown in Fig. 27.

CARBON FEED MECHANISMS

In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept at the proper distance apart by the operating mechanisms which must perform the following functions:

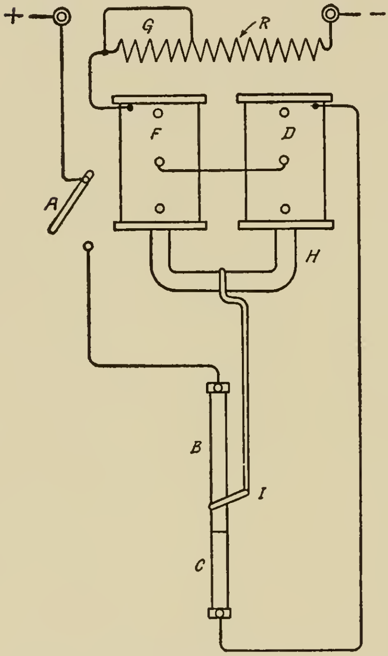


Fig. 28. Series Mechanism for D. C. Arc Lamp

(1) The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.

(2) They must be separated immediately afterward at the right distance to form a proper arc.

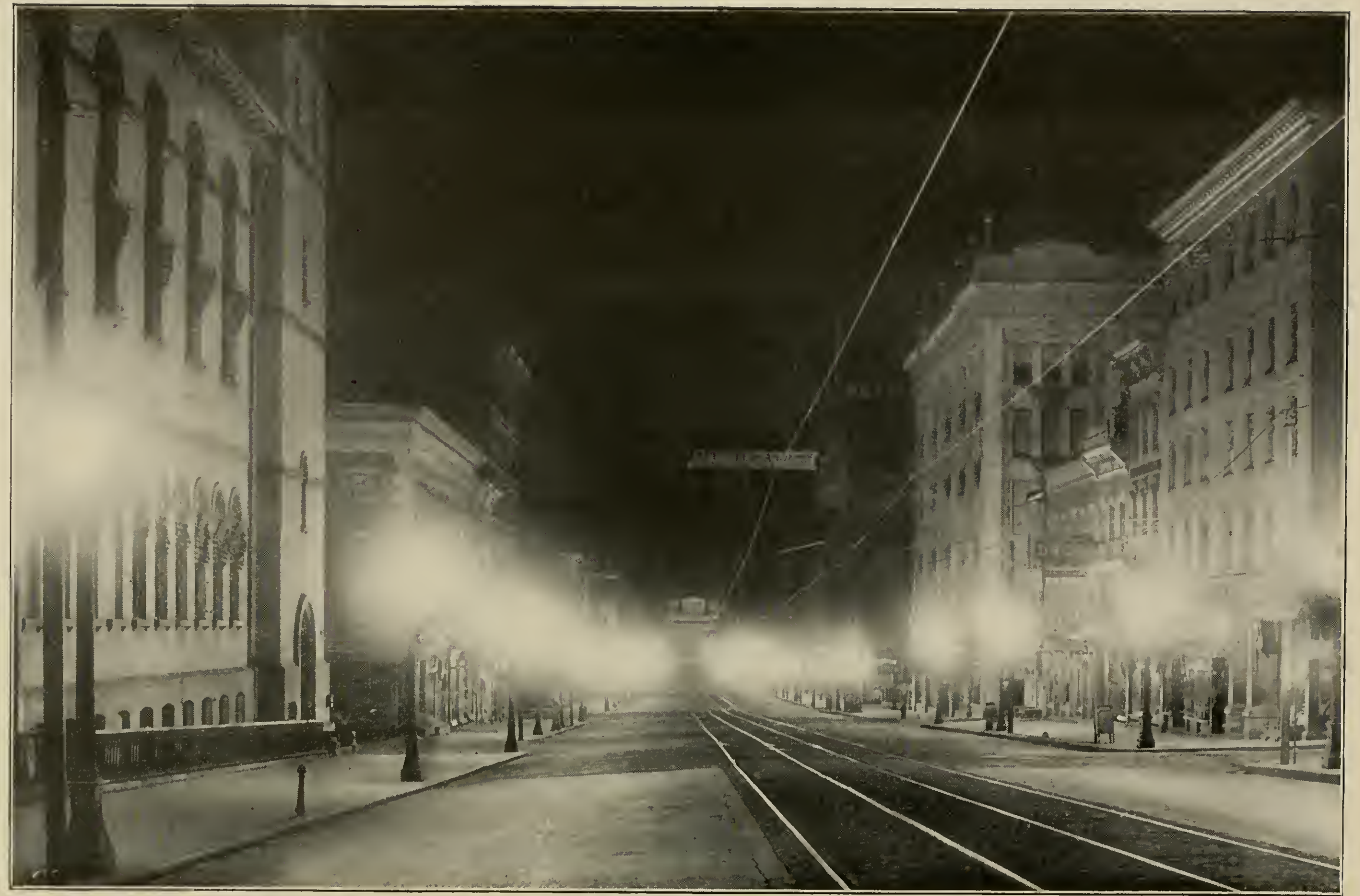
(3) The carbons must be fed to the arc as they are consumed.

(4) The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes: shunt, series, and differential mechanisms.

Shunt Mechanism. In shunt lamps, the carbons are held apart before the current is turned on and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the



MODERN STREET LIGHTING, SHOWING LUMINOUS-ARC LAMPS ON A STREET IN UTICA, NEW YORK

Courtesy of General Electric Company

start—450 ohms or more—and are difficult to start on series circuits, on account of the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

Series Mechanism. With the series-lamp mechanism, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current is lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

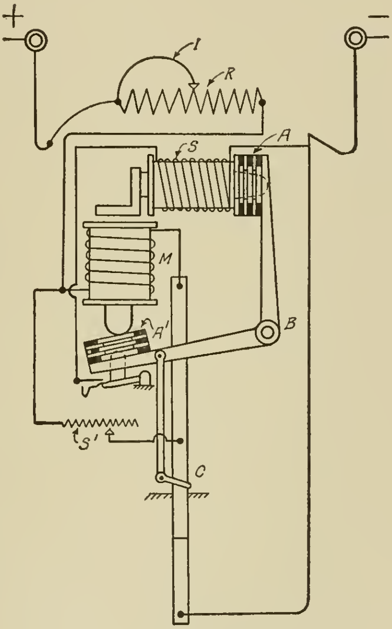


Fig. 29. Differential Mechanism for D. C. Arc Lamp

Fig. 28 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use on a direct-current constant-potential system. The symbols + and – refer to the terminals of the lamp and the lamp must be so connected that the current flows from the top carbon to the bottom one. *R* is a series resistance, adjustable for different voltages by means of the shunt *G*. *F* and *D* are the controlling solenoids connected in series with the arc. *B* and *C* are the positive and negative carbons respectively, while *A* is the switch for turning the current on and off. *H* is the plunger of the solenoids and *I* is the carbon clutch, this being what is known as a "carbon-feed lamp". The carbons are together when *A* is first closed; the current is excessive; and the plunger is drawn up into the solenoids, lifting the carbon *B* until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. *G* must be so adjusted that this point is reached when the arc is at its normal length.

Differential Mechanism. In the differential lamp, the series and shunt mechanisms are combined, the carbons being together at the start and the series coil arranged so as to separate them; while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range but it tends to aid the generator in its regulation.

Fig. 29 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for a direct-current constant-potential system. Here *S* represents the shunt coil and *M* the series coil, the armature of the two magnets *A* and *A′* being attached to a bell-crank, pivoted at *B*, and attached to the carbon clutch *C*. The pull of coil *S* tends to lower the carbon while that of *M* raises the carbon and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot, or some damping device, to prevent too rapid movement of the working parts.

TYPES

Classification. Arc lamps are constructed to operate on direct-current or alternating-current systems when connected in series or in multiple. They are also made in both the open and the enclosed forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing globe surrounds the arc and this globe is covered with a cap which renders it nearly air-tight. Fig. 30 is a good example of an enclosed arc as manufactured by the General Electric Company.

Direct-Current Arcs. *Open Type.* Open arcs for direct-current systems were the first to be used to any great extent. When used they are always connected in series and are run from some form of special arc machine, a description of which may be found in any book dealing with types of generators.

Each lamp requires in the neighborhood of 50 volts for its operation and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine but even this size of generator is not as efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp. The open arc lamp is used but little at present.

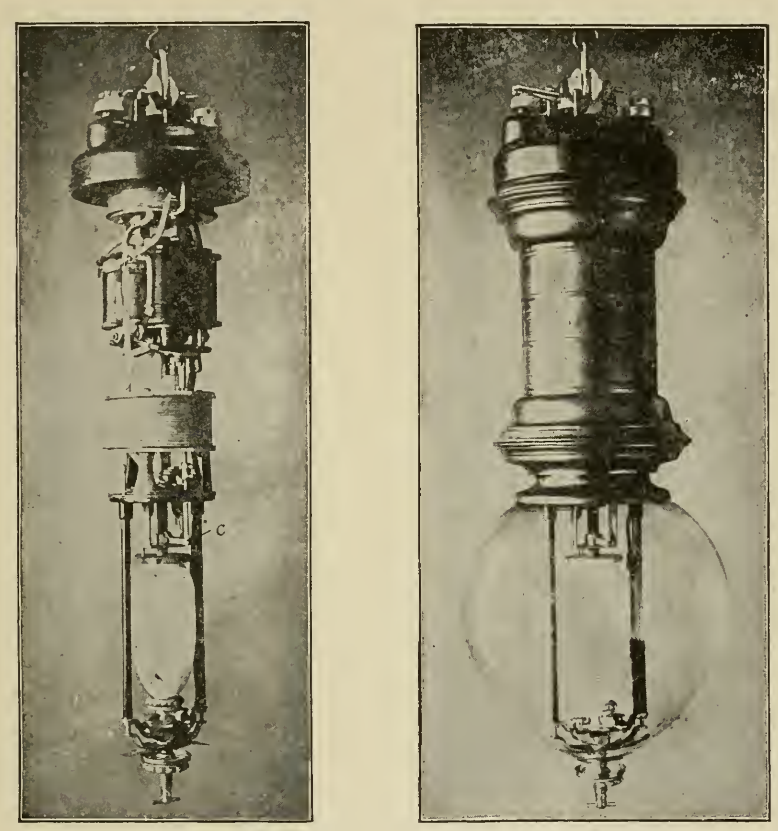


Fig. 30. Enclosed Arc Lamp Showing Carbon Feed Mechanism

Enclosed Type. Enclosed arcs for series systems are constructed much the same as the open lamp and are controlled by either shunt or differential mechanism. They require a voltage of from 68 to 75 at the arc and are usually constructed for from 5 to 6.8 amperes.

TABLE VII

Rating of Enclosed Arcs

D. C. Lamp	Current	Watts Consumed			Mean Intensity in H. U.			Mean Watts		
		In Lamp	In Arc	Mechanism	Spherical		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
					Opal Outer	Clear Outer	Clear Outer	Opal Outer	Clear Outer	Clear Outer
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp	Current	In Lamp	Power Factor Lamp	In Arc	Power Factor Arc	Mechanism						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U. Hefner Units.

They also require a constant-current generator or a rectifier outfit, if used on alternating-current circuits. Table VII gives some data as to the rating of enclosed arcs on constant-potential circuits.

Constant-Potential Type. Constant-potential arcs must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 30, one coil being located above, the other below the operating solenoids.

Alternating-Current Arcs. These do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated, or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant-potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arcs. There are in the market interchangeable arcs which may be readily adjusted so as to operate on either direct or alternating current and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light and the resulting illumination for the different lamps just considered will be taken up later. Aside from the distribution and quality of light, enclosed arcs have the advantage that the carbons are not consumed as rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without retrimming. The type of lamp most commonly employed requires 6.6 amperes for its operation.

FLAMING AND LUMINOUS ARC TYPES

Many thousands of enclosed carbon arc lamps, of both the direct-current and the alternating-current types are in use, and these lamps will be used to a considerable extent for some time to come; but other types of arc lamps, showing much higher efficiencies and having other very desirable characteristics, are now available and are replacing the carbon lamps in many instances. The high candle-power, high efficiency tungsten lamps are also used to replace carbon arcs in many instances.

Flaming Arc. In the carbon arc, the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different from carbon. The result of these experiments has been to place upon the market the flaming arc lamps and the luminous arc lamps—lamps of high candle-power and good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being either impregnated with certain salts which add luminosity to the arc, or else they are fitted with cores which contain the required material; the other class covers lamps which do not employ carbon, the most notable example being the magnetite arc which uses a copper segment as one electrode and a magnetite stick as the other electrode.

Bremer Type. The Bremer flaming arc lamp was introduced commercially in 1899 and, since some of its principles are incorporated in many of the lamps on the market today, it will be briefly described here. The diagram shown in Fig. 31 illustrates the main features of this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping it from creeping up and injuring the economizer and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

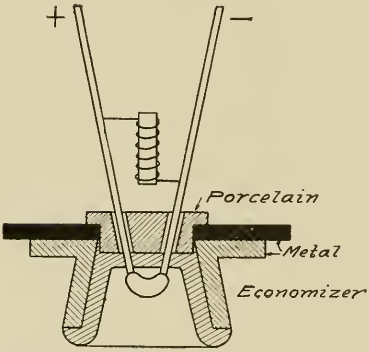


Fig. 31. Diagram of Bremer Flaming Arc

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps today differ greatly in their make-up. Some use impregnated carbons; others use carbons with a core containing the flaming materials; and metallic wires are added in some cases. The life of electrodes for flaming lamps depends upon their length and upon the type of lamp. The maximum life of the treated carbons is in the neighborhood of 100 hours.

Color of Arc. The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound and many of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced; while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. The distribution curves in Fig. 32 illustrate the relative economies of the different materials. Modern electrodes contain not more than 15 per cent of added material proportioned so as to give the color required for different effects.

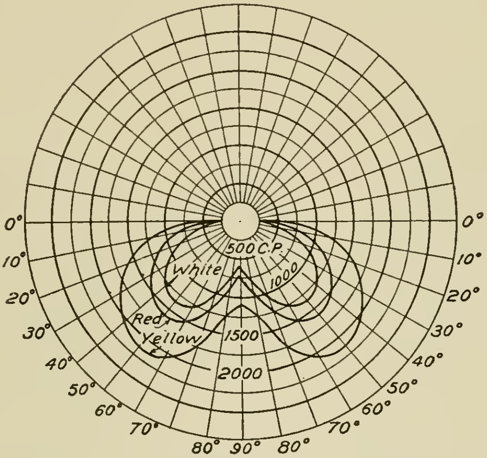


Fig. 32. Distribution Curves of a Flaming Arc

Characteristics and Advantages. The flaming arc lamp in some form is now manufactured by several firms. The modern lamp is known as the long-burning flame-carbon arc lamp. It possesses the following general characteristics: high efficiency, economical maintenance, steady burning, good light distribution, good color of light, comparatively low intrinsic brilliancy. In its most satisfactory form it is a lamp of comparatively high candle-power. Carbons for these lamps are from five-eighths inch to seven-eighths inch in diameter and the material for producing the flame is mixed with the carbon in the formation of the rods rather than introduced in the form of a core. The nature of the material used for impregnating the carbon determines the color given by the arc, as already explained.

TABLE VIII

Data for the Flaming Arc Lamps Compared in Fig. 35

	A. C. Series Lamp	D. C. Multiple Lamp
Terminal Volts	52	115
Terminal Watts	425	747.5
Arc Volts	46	70
Arc Watts	395	455
Amperes	10	6.5
Efficiency	93%	61
Power Factor	81.6%	......
Mean Hemispherical C. P.	1000	820
Mean Spherical C. P.	655	500
Mean H. S. C. P. per Watt	2.35	1.09
Mean Spherical C. P. per Watt	1.54	.67

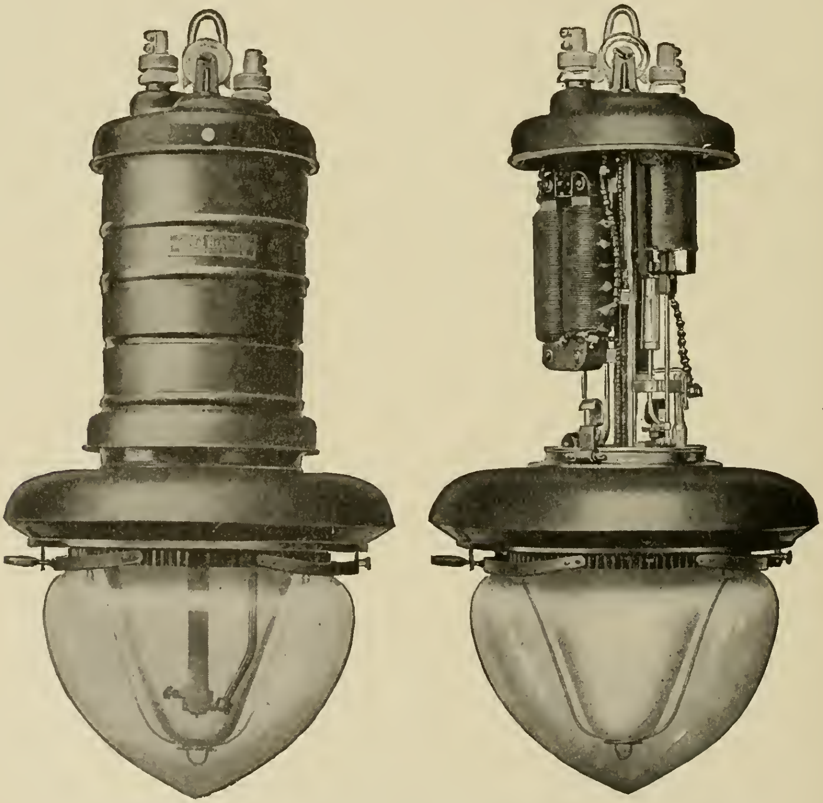


Fig. 33. Enclosed A. C. Series Flaming Arc Lamp with and without Hood
Courtesy of General Electric Company

The lamps are made for both direct-current and alternating-current operation. The best results are obtained with lamps requiring about 10 amperes for their operation and in these lamps the consumption of the carbons is at the approximate rate of one inch in 15 to 20 hours of burning. Lamps must be trimmed about every 100 hours.

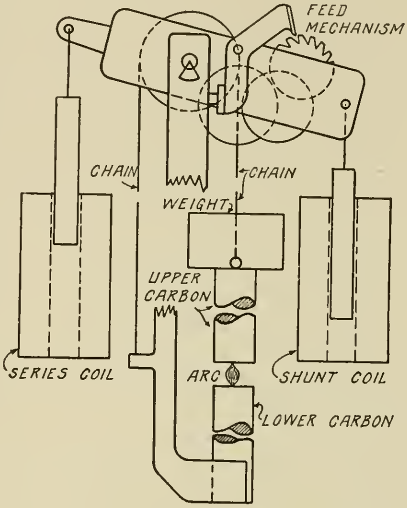


Fig. 34. Diagram Showing Principle of Sneak-Feed Mechanism for Flaming Carbon Arc Lamp

Special care is necessary in the design of flaming-carbon arc lamps to see that the "soot", or condensation of the arc fumes, is not deposited where it will interfere with the light given by the lamp, or with the operating mechanism.

Fig. 33 illustrates the flaming arc lamp, this particular figure showing types manufactured by the General Electric Company. Fig. 34 is a diagram of a "sneak-feed" mechanism used in one make of flaming arc lamp. Fig. 35 gives a comparison between a 6.5-ampere direct-current multiple lamp and a 10-ampere alternating-current series unit. Table VIII gives data relative to the two lamps compared

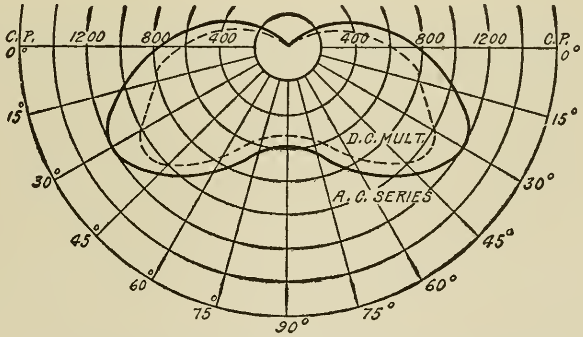


Fig. 35. Distribution Curves for Flaming Arc Lamps; D. C. Multiple Lamp for 6.5 Amperes; A. C. Series Lamp for 10 Amperes

in Fig. 35, and is illustrative of the performance of the modern unit. In general the modern type of lamp gives about 2.5 mean hemispherical candle-power per watt with "white" carbons and "Alba" glassware. With clear glassware the candle-power will run upwards of 5 mean hemispherical candle-power per watt consumption. "Yellow" carbons give from 30 to 50 per cent more light for the same energy consumption.

Luminous Arc. *Nature of Magnetite Electrodes.* The term luminous arc lamp is now reserved for the type of lamp at one time known as the "magnetite" or metallic arc lamp. Such lamps were introduced as early as 1903. The type most commonly employed uses a copper disc as one electrode and a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet-steel tube—as the other electrode. This lamp gives a luminous arc of high efficiency and as the magnetite electrode is not consumed rapidly, magnetite lamps do not require frequent trimming. The life of the magnetite electrode, as at present manufactured, is

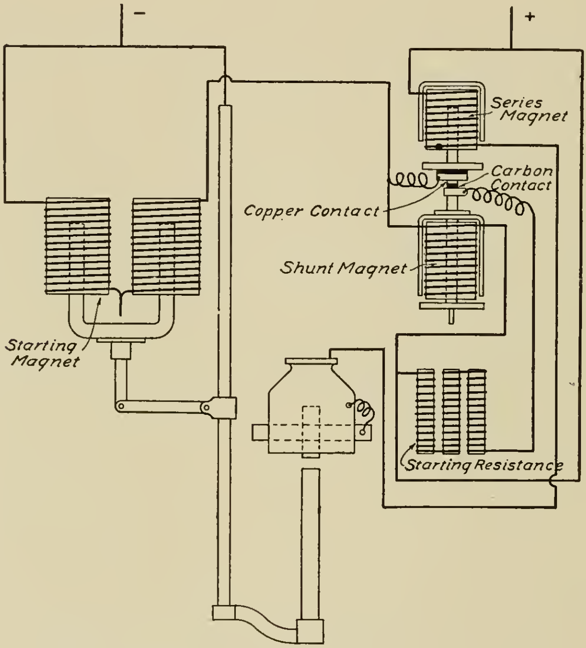


Fig. 36. Diagram of Connections for Luminous Arc Lamp

from 170 to 200 hours. A diagram of the connections of this lamp, as manufactured by the General Electric Company, is shown in Fig. 36. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor. Direct current must be used with this lamp, the current passing from the copper to the magnetite, and the light given by the lamp is white in color.

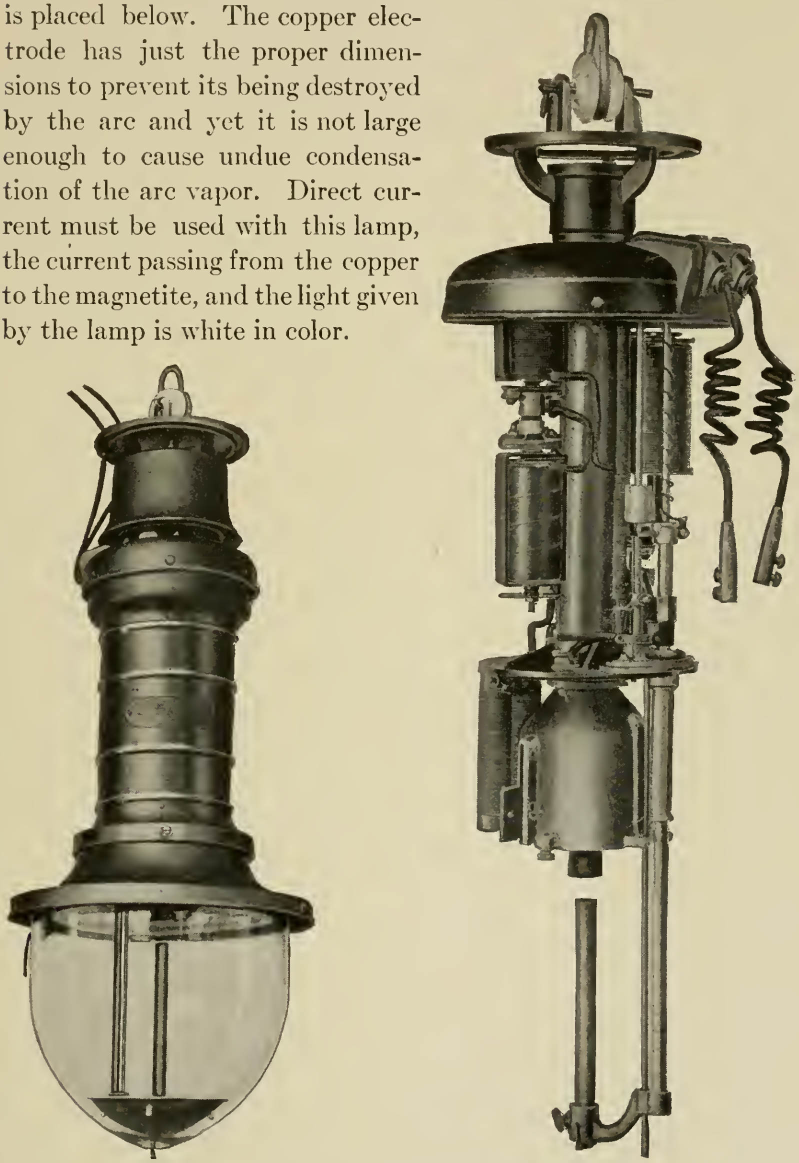


Fig. 37. Form 6 Series-Type 6.6-Ampere Luminous Arc Lamp
Courtesy General Electric Company

Specifications. The majority of the luminous arc lamps now in use (some 200,000) operate at about 75 volts at the arc and take 4 amperes, requiring 310 watts per unit. A 510-watt 6.6-ampere lamp is also standard. Fig. 37 illustrates the series luminous arc lamp as manufactured by the General Electric Company, and Fig. 38 shows the distribution curves for the 4-ampere and the 6.6-ampere units. The 4-ampere lamp gives a mean hemispherical candle-power of 545 while the 6.6-ampere unit gives a mean hemispherical candle-power of 1340. Metallic flame arc lamps are also made with a second metallic electrode used in place of the copper segment.

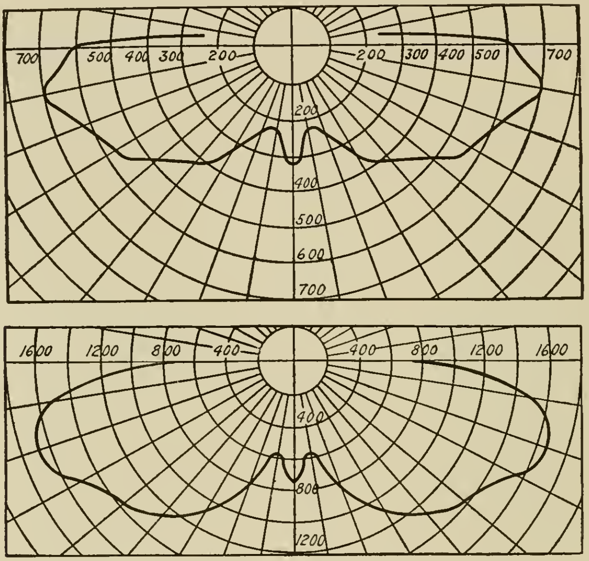


Fig. 38. Illumination Curves of 4-Ampere and 6.6-Ampere Luminous Arc Lamps

A very popular form of luminous arc lamp for ornamental street lighting is constructed with the controlling mechanism mounted below the arc proper and the lamp is enclosed in an ornamental globe and placed at the top of an ornamental standard.

Comparison of Arc Lamps. For the purpose of comparing the various types of arc lamps available, Table IX, prepared by Mr. S. W. Ash and published in the June, 1911, *Transactions of the Illuminating Engineering Society,* is given.

TABLE IX

Data on Arc Lamps

	Miniature Carbon 110 Volts 4 Amp. D. C.	Standard Multiple Carbon 110 Volts 5 Amp. D. C.	Standard Multiple Carbon 110 Volts 6½ Amp. D. C.	Intensified Arc 110 Volts 5 Amp. D. C.	Standard Multiple Carbon 110 Volts 6 Amp. 60 Cycle A. C.	Standard Multiple Carbon 110 Volts 7½ Amp. 60 Cycle A. C.	Twin Carbon multiple 220 volts 3½ Amp. D. C.	Standard Carbon 220 Volts 3¼ Amp. D. C.
Type of lamp..................	Miniature carbon	Standard multiple carbon	Standard multiple carbon	Intensified arc	Standard multiple carbon	Standard multiple carbon	Twin carbon multiple	Standard carbon
Volts at terminal.............	110 volts	110 volts	110 volts	110 volts	110 volts	110 volts	220 volts	220 volts
Volts at arc..................	83 volts	80 volts	80 volts	80 volts	72 volts	72 volts	2 arcs each 80 volts	150 volts
Current......................	4.1 amp. D. C.	5 amp. D. C.	6½ amp. D. C.	5 amp. D. C.	6 amp. 60 cycle A. C.	7½ amp. 60 cycle A. C.	3¼ amp. D. C.	3¼ amp. D. C.
Watts........................	451	550	715	550	430	540	715	715
Power factor..................					65%	65%		
Reflectors and glassware.........	White porcelain reflector, opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe
Electrodes....................	¼″ carbon	½″ carbon	½″ carbon	Two ¼″ upper ⅜″ lower carbons	½″ carbon	½″ carbon	(2 pair)½″ carbon	½″ carbon
Life of electrodes.............	50 hours	150 hours	100 hours	75 hours	125 hours	100 hours	150 hours	150 hours
Maximum, C. P..............	440 at 60 degrees below horizontal	400 at 30 degrees below horizontal	580 at 30 degrees below horizontal	600 at 55 degrees below horizontal	230 at 30 degrees below horizontal	310 at 30 degrees below horizontal	280 at 30 degrees below horizontal	240 at 30 degrees below horizontal
Mean spherical, C. P..........	218	215	318	225	160	215	195	160
Watts per M. S. C. P..........	2.06	2.56	2.25	2.44	2.68	2.51	3.75	4.44
Mean hemispherical, C. P.......	332	379	559	414	276	371	240	215
Watts per M. H. S. C. P........	1.36	1.45	1.28	1.33	1.56	1.45	3.05	3.43

TABLE IX—Continued

Data on Arc Lamps

	Series D. C. Open Carbon Arc 50 Volts 6.6 Amp.	Series D. C. Open Carbon Arc 50 Volts 9.6 Amp.	Series D. C. Enclosed Carbon Arc 75 Volts 6.6 Amp.	Series A. C. Enclosed Carbon 77 Volts 6.6 Amp.	Series A. C. Enclosed Carbon 77 Volts 7½ Amp. 60 Cycles	Flaming Arc 55 Volts 12 Amp. D. C.	Flaming Arc 55 Volts 12 Amp. A.C. 60 Cycles	Multiple Vertical Carbon Flame Arc 110 V. 6.5 Amp. D. C.
Type of lamp	Series D. C. open carbon arc	Series D. C. open carbon arc	Series enclosed carbon arc	Series A. C. enclosed carbon	Series enclosed carbon	Flaming arc	Flaming arc	Multiple vertical carbon flame
Volts at terminal	50 volts	50 volts	75 volts	77 volts	77 volts	55 volts	55 volts	110 volts
Volts at arc	48 volts	48 volts	73 volts	72 volts	72 volts	45 volts	45 volts	75 volts
Current	6.6 amp.	9.6 amp.	6.6 amp.	6.6 amp.	7½ amp. A. C. 60 cycles	12 amp.	12 amp.	6.5 amp.
Watts	330	480	495	425	480	660	500	715
Power factor				(Lamps only) 84%	(Lamps only) 84%		75%	
Reflectors and glassware	Clear outer	Clear outer	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflector, clear inner and outer globes	Light opal globe	Light opal globe	40" inverted diffuser alba globe
Electrodes	½" carbon (2 pair)	⅝" carbons (2 pair)	½" carbon	½" carbon	½" carbon	Yellow ¼"	Yellow ¼"	Upper ½" carbon lower only mineralized
Life of electrodes	18 hours	18 hours	125 hours	125 hours	100 hours	17 hours	17 hours	20 hours
Maximum, C. P.	720 at 45 degrees below horizontal	1250 at 45 degrees below horizontal	530 at 30 degrees below horizontal	250 at 20 degrees below horizontal	305 at 20 degrees below horizontal	2150 at 90 degrees below horizontal	1350 at 90 degrees below horizontal	2425 at 30 degrees below horizontal
Mean spherical, C. P.	265	460	290	144	173	1460	875	1129
Watts per M. S. C. P.	1.25	1.02	1.71	2.95	2.77	0.45	0.52	0.63
Mean hemispherical, C. P.	395	690	479	232	291	1890	1170	2058
Watts per M. H. S. C. P.	.82	0.71	1.03	1.83	1.65	0.32	0.39	0.35

TABLE IX—Continued

Data on Arc Lamps

	Multiple Flame 110 Volts 5.5 Amp. D. C.	Multiple Flame 110 Volts 7 Amp A. C. 60 Cycles	Series Vertical Carbon Flame Arc 78 Volts 6.6 Amp. D. C.	Series Flaming Arc 50 Volts 12 Amp. A. C. 60 Cycles	Series Luminous Arc 78 Volts 4 Amp. D. C.	Series Luminous Arc 78 Volts 6.6 Amp. D. C.	Multiple Luminous Arc, 110 Volts 6.5 Amp. D. C.
Type of lamp	Multiple flame	Multiple flame	Series vertical flame arc	Series flaming arc	Series luminous arc	Series luminous arc	Multiple luminous arc
Volts at terminal	110 volts	110 volts	78 volts	50 volts	78 volts	78 volts	110 volts
Volts at arc	70 volts	70 volts	75 volts	45 volts	75 volts	75 volts	75 volts
Current	5.5 amp. D. C.	7 amp. A. C. 60 cycles	6.5 amp. D. C.	12 amp.	4 amp. D. C.	6.6 amp. D. C.	6.5 amp. D. C.
Watts	605	525	510	440	310	510	715
Power factor		68%		75%			
Reflectors and glassware	Clear inner, opal outer porcelain enameled reflector	Porcelain enameled reflector, clear inner, opal outer globe	26" inverted diffuser alba globe	Opal outer	Clear outer	Clear outer	Clear globe
Electrodes	5/8" upper carbon 7/8" miner. lower	5/8" upper carbon 7/8" miner. lower	Upper 1/2" carbon lower only min.	Yellow	Upper copper slag, lower 1/2" magnetite	Upper copper slab, lower 11/16" magnetite	Upper copper slab, lower 1/2" magnetite
Life of electrodes	60 hours	50 hours	20 hours	12 hours	175 hours	125 hours	80 hours
Maximum, C. P.	1500 at 30 degrees below horizontal	1250 at 30 degrees below horizontal	2350 at 30 degrees below horizontal	1350 at 90 degrees below horizontal	700 at 10 degrees below horizontal	1650 at 10 degrees below horizontal	1650 at 10 degrees below horizontal
Mean spherical, C. P.	706	583	1223	875	285	720	720
Watts per M. S. C. P.	0.80	0.90	0.42	0.50	112	0.71	0.99
Mean hemispherical, C. P.	1210	875	2051	1170	545	1340	1340
Watts per M. H. S. C. P.	0.50	0.60	0.25	0.37	0.59	0.38	0.53

POWER DISTRIBUTION

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject; therefore, it will be treated very briefly here. The systems may be divided into:

(1) Series distribution systems.
(2) Multiple-series or series-multiple systems.
(3) Multiple or parallel systems.

They apply to both alternating and direct current.

Series System. The series distribution system is the simplest of the three; the lamps, as the name indicates, are connected in series as shown in Fig. 39. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

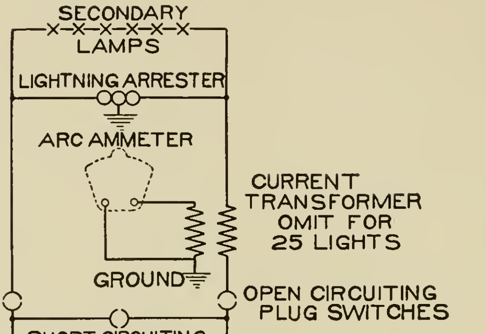


Fig. 39. Wiring Diagram for Single-Coil Transformer

Most Used for Street Illumination. The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and the saving of copper. The disadvantages are high voltage, as fixed by the number of lamps in series, the limitation of the size of the machines, since they cannot be insulated for voltage above about 6000; and the fact that a single open circuit shuts down the whole system.

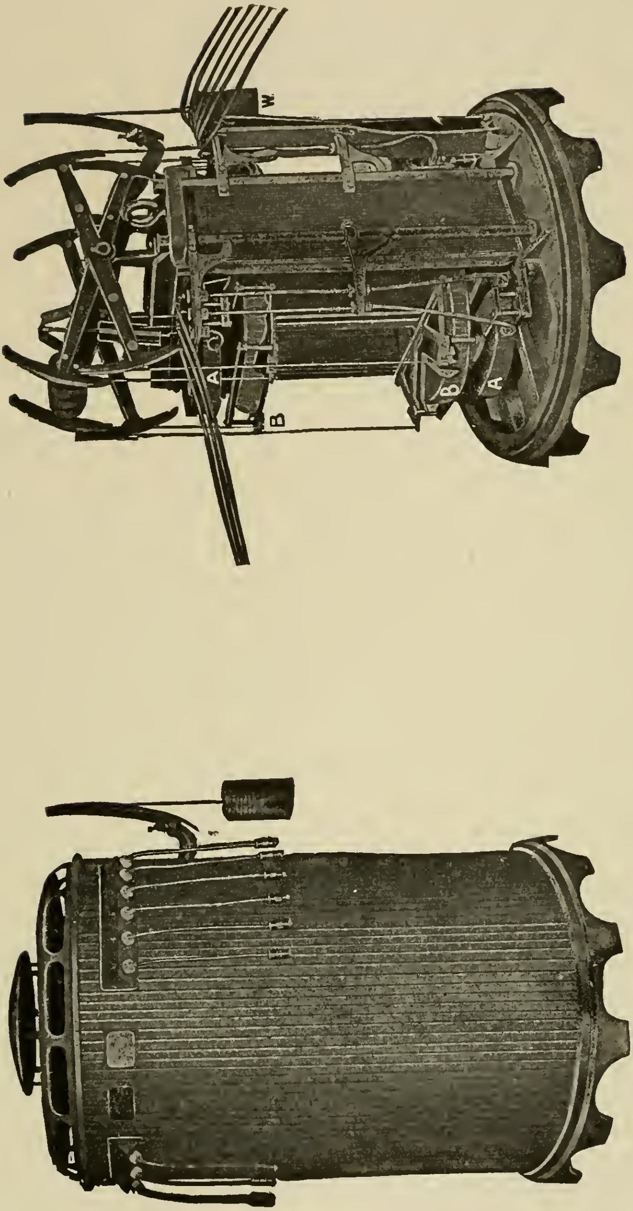


Fig. 40. Double-Coil Transformer (second view with case removed)

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of busbars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than one hundred 6.6-ampere lamps because of the high voltage which would have to be induced in the secondary for a larger number of lamps.

Description of Single-Coil Transformer for A. C. Series Circuits. Fig. 39 gives a diagram of the connection of a single-coil transformer in service. The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a "tub transformer". Fig. 40 shows such a transformer (double-coil type) when removed from the case.

Referring to Fig. 40, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient; hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils are brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

These transformers regulate from full load to one-third rated load within one-tenth ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96 per cent for 100-light transformers and 94.6 per cent for 50-light transformers at full load. The power factor of the system is from 76 to 78 per cent on full load and, owing to the great amount of magnetic leakage at less than full load—the effect of leakage being the same as the effect of an inductance in the primary —the power factor is greatly reduced, falling to 62 per cent at three-fourths load, 44 per cent at one-half load, and 24 per cent at one-fourth load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100 enclosed arcs of the 6.6 ampere size and they are also made for lower currents in the neighborhood of 3.3 amperes for incandescent lamps. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open-circuit voltages of the secondaries are as follows:

25-light transformer,	2300 volts	75-light transformer,	6900 volts
35- " "	3200 "	100- " "	9200 "
50- " "	4600 "		

The 50,- 75-, and 100-light transformers are arranged for multiple-circuit operation—two circuits used in series—and the voltages at full load reach 4100 for each circuit on the 100-light machine.

Constant Potential Transformer and Regulator for A. C. Series Circuits. The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system and allowing 83 volts for each lamp. In series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 41 shows such a regulator and Fig. 42 shows this regulator connected in circuit. The inductance is varied by the movement of the coil so as to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is

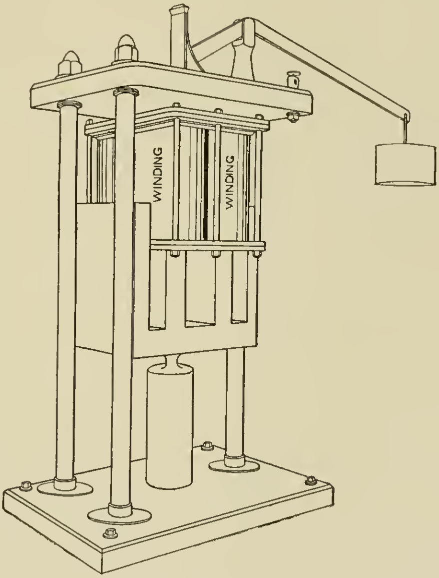


Fig. 41. Current Regulator for A. C. Series Distribution Systems

greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded; 60 to 65 lamps on a circuit is the usual maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Use of Mercury Arc Rectifier with Flaming or Luminous Arcs. The introduction of certain flaming or luminous arcs requiring direct current for their operation has led to the use of the mercury arc rectifier in connection with series circuits on alternating-current systems. A constant-current transformer is used to regulate for the proper constant current in its secondary winding and this secondary current is rectified by means of the mercury arc rectifier for the lamp circuit. In the recent outfits the rectifier tubes are immersed in oil for cooling. While this rectifier was first introduced for the operation of luminous arc lamps, there is no reason why it should not be used with any series lamp requiring direct current, provided the system is designed for the current taken by such lamps. With this system any commercial frequency may be used. Sets are constructed for 25-, 50-, and 75-light circuits. They have a combined efficiency-transformer and rectifier-tube, of 85 to 90 per cent, and operate at a power factor of from 65 to 70 per cent. Fig. 43 gives a diagram of the circuit and rectifier connections used with a single-tube outfit.

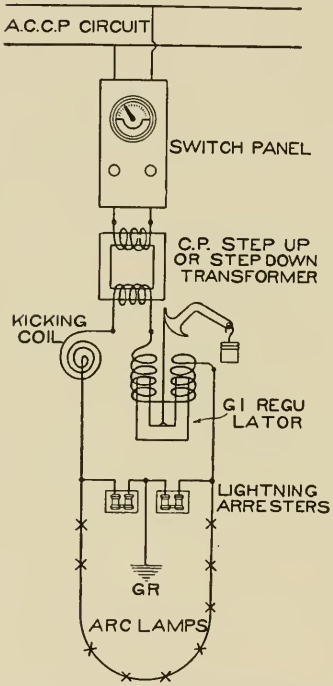


Fig. 42. Wiring Diagram Showing Introduction of the Current Regulator

Multiple=Series or Series=Multiple Systems. Multiple-series or series-multiple systems combine several lamps in series and these series groups in multiple, or several lamps in multiple and these multiple groups in series, respectively. They have but a limited application.

Multiple, or Parallel, Systems. *Characteristics of System.* By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the busbars at the station, or to the secondaries of constant-potential transformers. Fig. 44 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

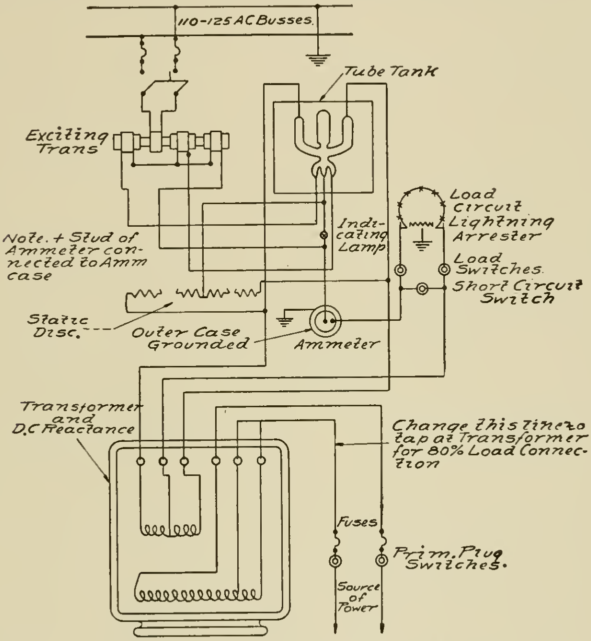


Fig. 43. Wiring Diagram for A. C. System Showing Mercury Arc Rectifier

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. To overcome this serious obstacle in multiple systems, various regulation schemes have been adopted.

Methods of Regulation. The regulating systems are as follows:

(1) Cylindrical conductors, parallel feeding.
(2) Conical conductors, parallel feeding.
(3) Cylindrical conductors, antiparallel feeding.
(4) Conical conductors, antiparallel feeding.

In the cylindrical-conductor parallel-feeding system, the conductors *AB* and *CD*, Fig. 44, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps *E* and a maximum at the lamps *F*, the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross section, or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

In an antiparallel system, the current is fed to the lamps from opposite ends of the system, as shown in Fig. 45.

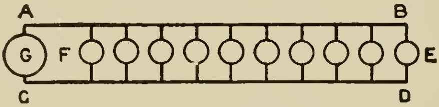


Fig. 44. Parallel Feeding System

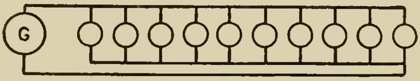


Fig. 45. Antiparallel Feeding System

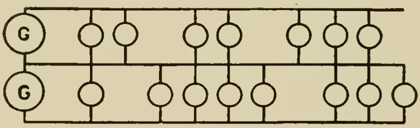


Fig. 46. Three-Wire System

Multiple=Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, 3- and 5-wire systems have been introduced, the 3-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor to the middle neutral conductor being the same as for a simple parallel system. Fig. 46 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a 2-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on "Power Transmission".

ILLUMINATION

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

Unit of Illumination. The unit of illumination is the *foot candle* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares—namely, that the illumination from a given source varies inversely as the square of the distance from the source—shows that the illumination at a distance of 2 feet from a single candle-power unit is .25 foot candle. For further consideration of the law of inverse squares, see "Photometry", p. 111.

Illumination may be classified as useful—when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight; and scenic—when used for decorative lighting, such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table X gives the intrinsic brightness of several light sources.

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection. Irregular reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough unpolished surfaces give such reflection. Smooth unpolished surfaces generally give a combination of two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of

TABLE X

Intrinsic Brightness of Light Sources

	Candle-power per Sq. In.
Moore tube	0.3 — 1.75
Frosted incandescent	2 — 5
Candle	3 — 4
Gas flame	3 — 8
Oil lamp	3 — 8
Cooper-Hewitt lamp	17
Welsbach gas mantle	20 — 50
Acetylene	75 — 100
Enclosed A. C. arc	75 — 200
Enclosed D. C. arc	100 — 500
Incandescent lamps	
Carbon 3.5 watts per candle	375
Carbon 3.1 watts per candle	480
Metallized carbon 2.5 watts per candle	625
Tantalum 2.0 watts per candle	750
Tungsten 1.25 watts per candle	875
Tungsten 1.15 watts per candle	1000
Nernst 1.5 watts per candle	2200
Sun on horizon	2000
Flaming arc	5000
Open arc lamp	10,000–50,000
Open arc crater	200,000
Sun 30° above horizon	500,000
Sun at zenith	600,000

interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semitransparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, the reflected light in interior lighting forms a large part of the source of illumination, this illumination will depend upon the nature and the color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table XI gives the amount of white light reflected from different materials.

From this table it is seen that the light-colored papers reflect the light well but, of the darker colors, only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value but this only holds when the material is free from dust. Rooms with

TABLE XI

Relative Reflecting Power

Material	%
White blotting paper	82
White cartridge paper	80
Chrome yellow paper	62
Orange paper	50
Yellow wall paper	40
Light pink paper	36
Yellow cardboard	30
Light blue cardboard	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Blue-green paper	12
Black paper	5
Black cloth	1.2
Black velvet	.4

dark walls require a greater amount of illuminating power, as will be seen later.

RESIDENCE LIGHTING

Types of Lamps. The lamps used for residence lighting are limited to the less powerful units—namely, carbon or tungsten lamps varying in candle-power from 8 to 40 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc lamps with incandescent lamps might be mentioned, the arcs being so much whiter than the incandescent lamps that the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. *Point-by-Point Method.* In determining the value of illumination, not only the candle-power of the units but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \dfrac{1}{1-k}}{d^2}$$

I is illumination in foot candles; $c.p.$ is candle-power of the unit; k is coefficient of reflection of the walls; d is distance from the unit in feet.

Where several equal units are used, this formula becomes

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + ---------- \right) \frac{1}{1-k}$$

or

$$c.p. = \frac{I}{\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + ---------- \right) \frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given on page 64.

Correction for Angle of Lights with Plane of Illumination. The above method is not strictly accurate because it does not take account of the angle at which the light from each one of the sources strikes the assumed plane of illumination. If the ray of light is perpendicular to the plane, the formula $I = \frac{c.p.}{d^2}$ gives correct values. If a is the angle which the ray of light makes with a line drawn from the light source perpendicular to the assumed plane, then the formula becomes

$$I = \frac{c.p. \times \cos a}{d^2}$$

Therefore, by multiplying the candle-power value of each light source in the direction of the illuminated point by the cosine of each angle *a*, a more accurate result will be obtained.

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of *k*, in the above formula, will vary from 60 per cent to 10 per cent, but for rooms with a fairly light finish 50 per cent may be taken as a good average value.

Amount of Light Necessary. The amount of illumination will depend on the use to be made of the room. One foot candle gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 foot candle on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 foot candles up, while that due to moonlight is in the neighborhood of .03 foot candle. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

The method of calculating the illumination of a room that has just been described is known as the *point-by-point* method and it gives very accurate results, if account is taken of the angle at which the light from each source strikes the plane of illumination and if the light distribution curves of the units and the value of *k* have been carefully determined. Under these conditions, however, the calculations become extended and complicated, and methods only approximate, but simpler in their application, are being introduced. One method, which gives good results when applied to fairly large interiors, makes the flux of light from the light sources the basis of calculation of the average illumination.

Flux of Light Method. Flux of light is measured in lumens and a lumen is the amount of light which must fall on one square foot of surface in order to produce a uniform illumination of an intensity of one foot candle. A source of light giving one candle-power in every direction and placed at the center of a sphere of one foot radius would give an illumination of one foot candle at every point in the surface of the sphere and the total flux of light would be 4π, or 12.57 lumens, since the area of the sphere would be 4π, or 12.57 square feet. A lamp giving one mean spherical candle-power gives a flux of 12.57 lumens and the total flux of light from any source is obtained by multiplying its mean spherical candle-power by 12.57. In calculating illumination it is customary to determine the illumination on a plane about 30 inches from the floor for desk work, and about 42 inches from the floor for the display of goods on counters. If we determine the total number of lumens falling on this plane and divide this number by the area of the plane, we obtain the average illumination in foot candles. This of course tells us nothing about the maximum or minimum value of the illumination and such values must be obtained by other methods, if they are desired. Reflected light, other than that covered by the distribution curve of the light unit including its reflector, is usually neglected in this method of calculation.

We may assume that in large rooms the light coming from the lamp within an angle of 75 degrees from the vertical reaches the plane of illumination. In smaller rooms this angle should be reduced to about 60 degrees. In order to determine the flux of light within this angle a Rousseau diagram, which is described later, should be drawn. By means of this diagram the average candle-power of the light source within the angle assumed may be readily determined, and this mean value, multiplied by 12.57, will give the flux of light in lumens. This method of calculation, together with some guides for its rapid application, is described by Messrs. Cravath and Lansingh in *Transactions of the Illuminating Engineering Society:* 1908. The same authorities give the following useful data:

To determine the watts required per square foot of floor area, multiply the intensity of illumination desired by the constants given, as follows:

INTENSITY CONSTANTS FOR INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet......	.25
Same with very light walls..	.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enameled; large room; light ceiling; dark walls; lamps pendant, height from 8 to 15 feet.....................	.29
Same with very light walls..	.23
Gem lamps rated at 2.5 watts per horizontal candle-power; clear prismatic reflectors, either concentrating or bowl; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet.......	.55
Same with very light walls..	.45

Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.65
Same with very light walls	.55
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height from 10 to 14 feet	.75 to 1.5
Same; small room; medium walls	1.25 to 2.0
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.70
Same with light walls	.60

INTENSITY CONSTANTS FOR ARC LAMPS

5-ampere, enclosed direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; light ceiling; medium walls; height from 9 to 14 feet	.50

Lighting Arrangement. An arrangement of lamps giving a uniform illumination cannot well be applied to residences on account of the number of units required and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is recommended. In any case where the coefficient of reflection of the ceilings is less than 40 per cent, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

Illumination of Room for Different Arrangements of Lamps. As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50 per cent. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 foot candle is required at the corner of the room, we have the equation (point-by-point method)

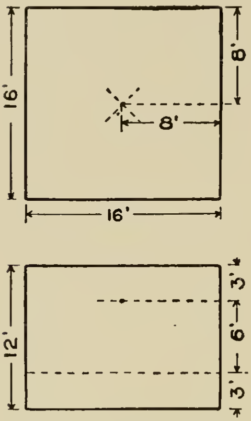


Fig. 47. Diagram Showing Method of Calculating Room Illumination

$$.5 = c.\ p. \frac{1}{12.8^2} \times \frac{1}{1-.5}$$

since $d = \sqrt{8^2+8^2+6^2} = 12.8$ (See Fig. 47). Solving for the value of *c. p.*, we have

$$c.\ p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

To determine the illumination directly under the lamp, we have

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1-.5} = \frac{48}{36} \times 2 = 2.7 \text{ ft.-candles.}$$

This value is five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor, as shown in Fig. 48. Calculating the illumination at the center of the room on a plane 3 feet above the floor, we have

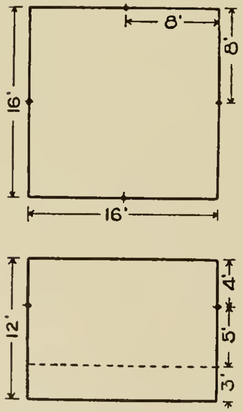


Fig. 48. Diagram for Four 8-C.P. Lamps on Side Wall

$$I = 8\left(\frac{1}{89}+\frac{1}{89}+\frac{1}{89}+\frac{1}{89}\right)\frac{1}{1-.5}$$

$$d^2 = 8^2+5^2 = 64+25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ foot candle}$$

The illumination at the corner of the room would be

$$I = 8\left(\frac{1}{89}+\frac{1}{89}+\frac{1}{345}+\frac{1}{345}\right)\frac{1}{1-.5}$$

$$= 8\left(\frac{2}{89}+\frac{2}{345}\right) \times 2 = .45 \text{ foot candle}$$

In a similar manner the illumination may be calculated for any point in the room or a series of points may be taken and curves

TABLE XII

A Typical Residence Installation

Room	No of Lights	Globe or Reflector	Remarks
Hall (front) 10′×4′ 6″	1 10-watt Mazda	Opalescent enclosing globe	Walls dark green, ceiling white Lamp 7′ above floor
Living room 13′×14′	1 60-watt Mazda 2 15-watt Mazda portable	Semi-indirect opalescent bowl	Walls dark green, ceiling white Lamp 7′-6″ above floor
Dining room	1 60-watt Mazda 3 15-watt Mazda	Dome with silk diffusing screen underneath Back of art-glass window	Lamp 4′-9″ from floor
Den 11′×10′	1 100-watt Mazda 1 25-watt desk lamp	Total indirect lighting fixture	Walls dark green, ceiling white Lamp 7′-3″ above floor
Pantry	1 15-watt Mazda	Semi-indirect, opalescent bowl	Walls buff, ceiling white
Hall (rear)	1 15-watt Mazda	Lamp frosted, opal shade	Lamp 7′-6″ above floor
Bathroom 9′×6′	1 25-watt Mazda 1 25-watt Mazda	Opalescent glass, bowl-shaped reflector Metal reflector	Bracket lamp 5′-6″ from floor Mounted at right of mirror
Bedroom 10′×14′	1 15-watt Mazda 1 40-watt Mazda	Cylindrical diffusing shade Deep bowl-shaped diffusing shade	Bracket lamp Ceiling lamp 7-′8″ above floor
Kitchen 9′×11′	1 40-watt Mazda	Extensive prismatic reflector	Lamp 7′-6″ from floor

plotted, showing the distribution of the light as well as the areas having the same illumination. Where refined calculations are desired, the correct distribution curve of the lamp must be made use of in order to determine the candle-power in different directions in the room.

Illumination Calculations After Lights Are Installed. By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an important one and it may be desirable to determine, by calculation, the illumination curves for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting. The point-by-point method of calculation is used for very accurate work when the system of illumination admits of this method. Other methods are often simpler and sufficiently accurate for practical work.

Typical Arrangement for Small Residence. In house lighting the decorative element predominates, yet the illumination should be satisfactory and the system should be economical in its operation. As typical of a satisfactory and inexpensive lighting system in a small residence, Table XII, compiled for an article, by Mr. A. L Powell, published in the *Transactions of the Illuminating Engineering Society,* is given.

Rules for Good Residence Illumination. Before passing on to the subject of the lighting of larger interiors it would be well to call attention to some of the salient points of good lighting as they are set forth in the little primer on illumination, "Light: Its Use and Misuse", published by the Illuminating Engineering Society, New York City, as these principles apply very directly to the plans for residence lighting systems:

Illumination cannot be judged by the brightness of lamps.

Flickering sources of light are to be avoided.

The eyes should not be subjected to an unshaded lamp.

Light should come from above the eyes, not from below or on a level with the eyes.

Place lamps so that one does not have to face them when reading.

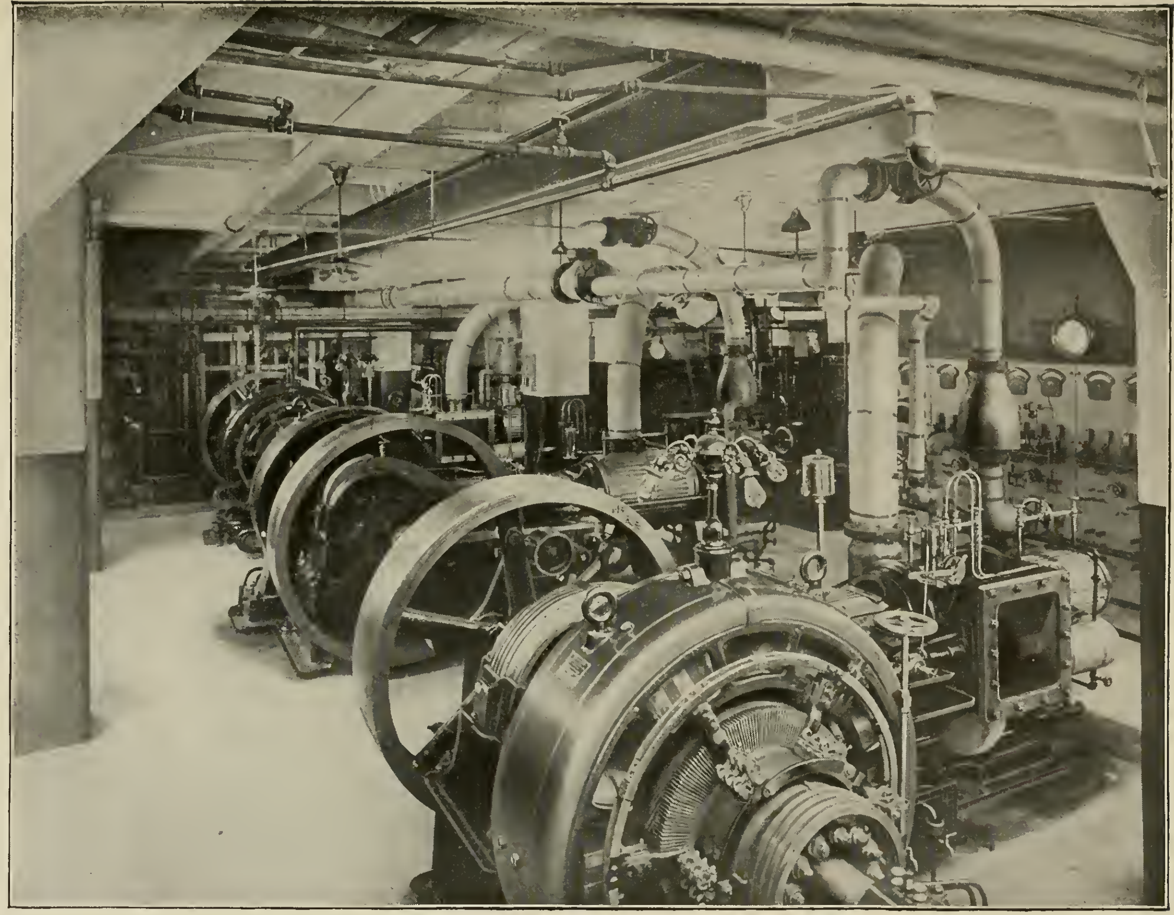
Do not use a bright light against a dark background.

Do not use local lighting alone; provide for a general illumination and then add local lighting as needed.

Use care in the selection of reflectors. Modern globes and reflectors are scientifically designed for given conditions and should be used as planned by their makers.

Light walls and lightly tinted shades are preferred.

Most work can be carried on with an illumination of from 2 to 3 foot candles Fine-print reading and sewing require perhaps 5 foot candles. From 7 to 10 foot candles is ample for drafting, engraving, etc.



INSTALLATION OF THREE TANDEM-COMPOUND SKINNER ENGINES DIRECT CONNECTED TO GENERATORS

Courtesy of Skinner Engine Company

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Variations from Residence Problem. Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light; and, again, the distance of the light sources from the plane of illumination is generally greater, if an artistic arrangement of the lights is planned. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illumination of .5 foot candle for the ground illumination may be taken as a minimum.

Use of Larger Units. In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper-Hewitt lamp is being employed. High candle-power reflector lamps, such as the tungsten lamp, are being used to a large extent for offices and drafting rooms.

Choice of Type of Unit. The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light—doing away with the strong shadows due to portions of the lamp mechanism—and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are sometimes preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows, but the color of the tungsten lamp is a great improvement over the carbon lamps previously used.

Location of Lights. In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

Arcs. When arcs are used they should be placed fairly high—20 to 25 feet when used for general illumination and when the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from 12 to 15 feet above the floor, and special care must be taken to diffuse the light.

Incandescents. Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling Lights. Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Indirect Lighting. Indirect lighting is employed to some extent. By indirect lighting we mean a system of illumination in which the light sources are concealed and the light from them is reflected to the room by the walls, or ceilings, or other surfaces; or in which the light sources are placed above a diffusing panel. In the latter case the diffusing plate appears to be the source of light. In some cases the walls themselves are shaped and constructed so as to form the reflectors for the light units (cove lighting), but in others all of the reflecting surfaces, except the side walls and ceiling, are made portions of the lamp fixtures.

Semi-Indirect Lighting. Semi-indirect fixtures are now available. These allow a portion of the light to be diffused and thrown directly on the plane to be illuminated but a large portion of the light is thrown to the ceiling, or to a special reflector taking the place of the ceiling, and from there reflected to the points where the light is required. Fixtures of this nature will be illustrated in the section on shades and reflectors. The following points may be noted when considering direct, semi-indirect, and indirect systems of lighting:

Direct vs. Indirect Lighting. Direct systems are usually the most economical; semi-indirect next; and indirect systems the least economical for a given illumination. The matter of uniform illumination follows the reverse order, direct lighting giving the least uniform effects. The disadvantage of the indirect systems comes from the loss of light through the agency of the required reflecting surfaces. There is also a possibility in indirect systems of lighting of too uniform and too shadowless an illumination, the effect of which is very trying on the eyes. Experiments show that a system using about 15 per cent of the light as coming directly from the light source is more satisfactory than totally indirect systems for the average installation.

For indirect systems the ceilings should be very light in color; with clean white calcimine ceilings the coefficient of reflection will vary from 73 to 78 per cent, depending upon the angle at which the light strikes the ceiling, and the condition of the surface, whether rough or smooth. Fig. 49 shows a distribution curve for a light unit which is considered as ideal for semi-indirect lighting. Distribution curves as obtained in practice will be illustrated in the section covering shades and reflectors.

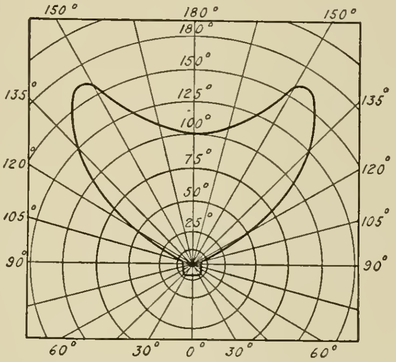


Fig. 49. Prototype Curve for Semi-Indirect Lighting. Scale 100 Unit Directly Upward

Methods of Calculating Illumination. The methods of calculating illumination or of determining the lamps required to give a certain illumination are not different from those already outlined in connection with residence lighting. The point-by-point method may be used, and, with the aid of properly prepared tables of constants, cosines, etc., the work is rendered less burdensome, but the flux-of-light method involves less of numerical calculation and gives excellent results in the majority of cases. Of the various methods of procedure which might be followed in making calculations by the flux-of-light method only one will be illustrated here.

Typical Calculation by Flux-of-Light Method. Assume a room 40′ by 80′, ceiling 15′ high, with medium light walls and ceilings to be lighted with an average intensity of 3 foot candles on a

TABLE XIII

Percentage of Total Lumens from Light Sources Which Are Effective under Different Conditions

Walls	Ceiling	REFLECTORS						
		Bare Lamp	Prismatic Clear	Prismatic Sanded	Steel Porcelain and Aluminum	Opal	White Glass of Light Density	Indirect and Semi-Indirect
		(Percentage of Lumens Effective)						
Light	Light	41	60	51	48	50	48	31
Medium	Light	35	53	47	46	45	44	28
Light	Medium	34	52	47	47	44	43	21
Dark	Light	30	48	43	44	42	40	25
Medium	Medium	30	48	43	45	42	40	19
Dark	Medium	25	45	40	44	40	36	17
Dark	Dark	21	40	36	44	37	33	10

plane of illumination $2\frac{1}{2}$ feet from the floor. There will be required $3 \times 40 \times 80$, or 9600 effective lumens. The relation between effective lumens and total lumens of light sources must next be known in order that we may find the total lumens to be given by all of the lamps. Table XIII gives very useful data in this connection (Mazda lamps assumed).

Likewise, in order to get the total candle-power rating of our required lamps, we must know the total lumens given by the different sizes of units. These values are given in Table XIV.

TABLE XIV

Total Lumens, Average, for Mazda Lamps, Based on Lamp Life of 1000 Hours

Rating	Total Lumens, Average
25	189
40	323
60	505
100	842
150	1262
250	2195
400	3512
500	4390

A reflector, say of the clear prismatic type, must first be assumed; then from Table XIII we see that for such a reflector with medium walls and ceilings, only 48 per cent of the total

TABLE XV

Required Intensity of Illumination

Place to be Lighted	Foot Candles Required
Auditoriums, theaters	1 — 3
Bookkeeping rooms	3 — 5
Corridors, halls	.5 — 1
Depots, assembly halls, and churches	.75— 1.5
Drafting rooms	5 — 10
Desk lighting	2 — 5
Engraving rooms	5 — 10
Factories, general, where individual drops are used	2 — 3
Factories, complete, no individual drops	4 — 5
Hotel halls	1 — 1.5
Hotel rooms	2 — 3
Offices (waiting rooms)	1.25— 2.5
Offices (private)	2 — 3
Offices (general)	3 — 4
Offices (where desk lights are used)	1.5 — 2.5
Postoffices	2 — 5
Reading rooms	1 — 3
Residences	1 — 3
Stores (light goods)	2 — 3.5
Stores (dry goods)	4 — 6
Stores (clothing)	4 — 7
Store windows	5 — 20
School rooms	2 — 3
Saloons, cafes, depending on effects	2 — 5
Stations (waiting rooms)	1.5 — 2.5
Train sheds	1.5 — 2
Warehouses	1.5 — 2

lumens are effective; therefore the total lumens must be the required lumens, 9600, divided by 0.48, or 20,000 lumens. By dividing the total of 20,000 by the total lumens of each size of lamp we can get the required number of lamps of that rating which will be required.

For uniform illumination a large number of small units should be used, but local conditions and first cost of installation are important points; and the remainder of this problem will be considered on the assumption that 16 outlets are provided, each fitted with a 150 c. p. unit, and that the outlets are uniformly spaced, the distance between the lamps being 14 feet. Of the prismatic reflector selected there are three types and the type of reflector and the proper mounting height remain to be determined. The ratio of mounting height to distance between lamps is given for the three types of reflector as follows: extensive, 1–2; intensive, 4–5; focusing,

TABLE XVI

Cooper-Hewitt Lamps

Service	Height of Lamp	C. P. of Unit	Av. Area per Lamp in Square Feet
Foundry	10–15 ft.	300	900
Foundry	20–25 ft.	700	2250
Machine shop	10–15 ft.	300	500
Erecting shop	20–30 ft.	700	1250
Drafting room	15 ft.	300	300
Drafting room	20 ft.	700	400
Offices	10–15 ft.	300	400
Offices	20–25 ft.	700	750
Ordinary labor	10–15 ft.	300	1100
Ordinary labor	20–25 ft.	700	2750

4–3. Extensive reflectors would be mounted 9.5 feet from the floor, which might perhaps be too low. Focusing reflectors could not be used to advantage and intensive reflectors should be mounted 13½ feet above the floor; hence the intensive type of reflector works out to the best advantage for our assumed installation.

Required Illumination for Different Locations. As a guide to good illumination values to be assumed for different types of interiors, the following table, Table XV, may be used.

In general, the greater the candle-power of the unit used the higher the units must be mounted to give good lighting effects. For illuminating interiors with arc lamps, the specific distribution curve of the unit—curves of the form shown in connection with the section on arc lamps—should be known and the point-by-point method of calculation can be used, or the number of lumens within the useful angle can be calculated by means of the Rosseau diagram, p. 124 and the flux-of-light method p.p. 62 and 69. Table XVI gives some useful information covering the mercury vapor lamp and Table XVII is a guide to the use of ordinary arc lamps. Reference should be made to Table IX for a comparison of ordinary arcs with the newer types.

In factory and drafting-room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Special Cases. If space permitted, the details of lighting systems covering rooms used for a wide variety of purposes might

TABLE XVII

Lighting Data for Arc Lamps

Place Lighted	Clothing Store	Weave Room	Erecting Room	Machine Shop	Drafting Room	Drafting Room	Ship Shed	Cataloging Dept	Jewelry Store
No. of sq.ft. of space lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used.	12	50	200	42	27	24	50	17	6
Circuit.	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series	D. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult
Cycles.	60	. . . . .	. . . . .	. . . . .	60	. . . . .	. . . . .	. . . . .	. . . . .
Volts, line	104	110	120	120	. . . . .	120	220	110	110
Amperes.	6	$3\frac{1}{4}$	6.2	6.2	7.5	4	6	$4\frac{1}{2}$	5
Volts at arc.	72	75	80	80	72	80	80	80	80
Power factor of lamp.	.69	. . . . .	. . . . .	. . . . .	.86	. . . . .	. . . . .	. . . . .	. . . . .
Watts per lamp.	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.). . .	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation).	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation).	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp. . .	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp. . . .	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe.	Opal.		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ White	Saw Toothed	Trussed	Trussed	12′ white	Trussed	160′ Trussed	13′ 9″ Maroon	16′ 10″ White
Reflector system used.	Steel Concentric Diffuser	Adjust. Diffuser	9″ Mirror	9″ Mirror	Concentric Diffuser	16 Adj. Dif 8 Con. Dif	12″ Mirror	Concentric Diffuser	Concentric Diffuser
Height of arc from floor. . .	9′-6″	12′ to 15′	46′	47′	9′	15′	150′	10′-7″	13′-2″
Distance between lamps. . .	14′ to 18′	24′	32′ to 38′	30′-9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

be included. Many of the problems that come up can be satisfactorily met by one of several possible installations and the lighting of interiors is, as a whole, an art as well as a science. The reader is referred to the details of good lighting systems, as they appear from time to time in the technical press, for a more intimate knowledge of the manner in which the principles, as given here, are applied to everyday practice.

Theater lighting becomes a special problem, as does show window and sign lighting, as well as all forms of spectacular lighting; all are problems for which it is difficult to lay down any special rules other than the general ones covering illumination, as they have already been given.

STREET LIGHTING

Nature of Problem. In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

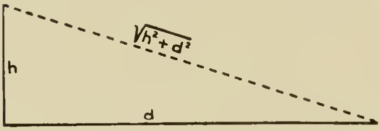


Fig. 50. Diagram for Calculating Street Light Illumination

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination of a plane normal to the rays of light is given by the formula

$$I=\frac{c.p.}{h^2+d^2}$$

when I is illumination in foot candles; $c.\ p.$ is candle-power of the unit, determined from the distribution curve of the lamp; h is distance the lamp is mounted above the ground, in feet; and d is distance from the base of the pole supporting the lamp to the point where the illumination is being considered, Fig. 50.

While this will give the illumination in foot candles, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 foot candles would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

Ideal and Actual Distribution Curves. Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 51.

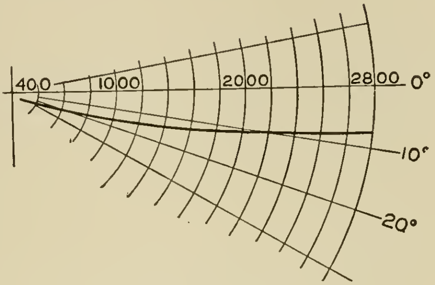


Fig. 51. Ideal Distribution Curve for a Street Light

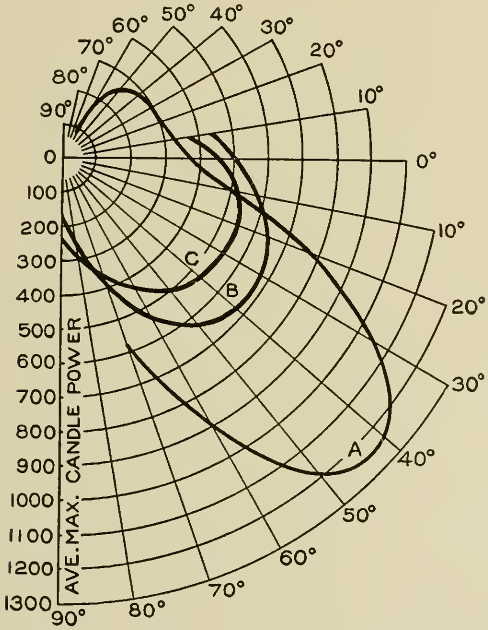


Fig. 52. Distribution Curves for Commercial Arc Lamps Used in Street Lighting

Actual distribution curves taken from commercial arc lamps are shown in connection with the arc lamp described in the section on this subject. As illustrative of the use of such curves Figs. 52 and 53 are included.

Curve A shows distribution curve for a 9.6-ampere, open direct-current arc.

Curve B shows distribution curve for a 6.6-ampere, d. c. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, a. c. enclosed arc.

Globes used with B and C are opal inner globes, clear outer globes.

Globes used with A are clear outer globes.

A street reflector was used with the enclosed arcs.

Illumination Curves. A series of curves known as "illumination curves" may be readily calculated, showing the illumination in foot candles at a given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 52 are given in Fig. 53 where *A′*, *B′*, and *C′* correspond to *A*, *B*, and *C* in Fig. 52. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps fitted with suitable reflectors are shown in Fig. 54.

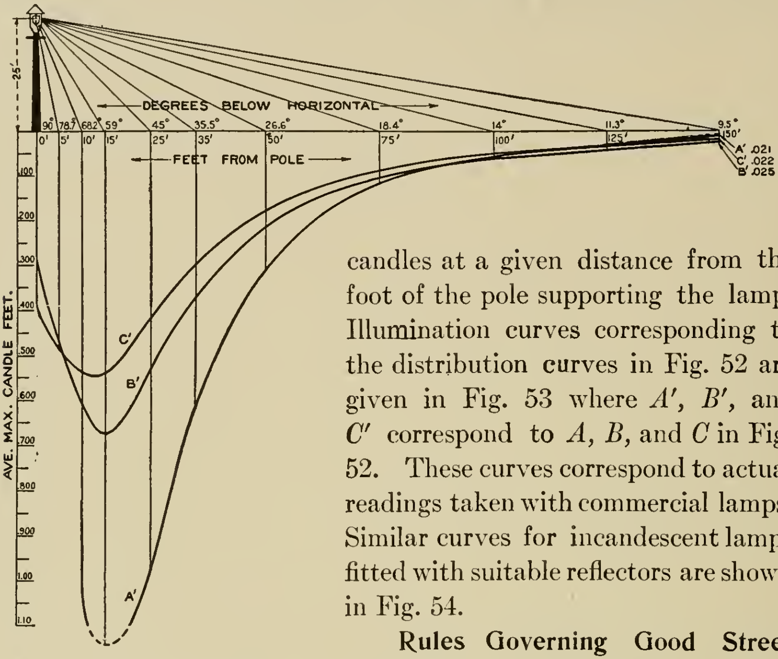


Fig. 53. Illumination Curves Drawn from Data Given in Fig. 52

Rules Governing Good Street Lighting. The principal considerations in street lighting other than ornamental street lighting are:

A sufficient amount of light must be supplied and distributed so as to give a fairly uniform distribution.

Lamps should have as low an intrinsic brilliancy as is practical—all questions, including economy, considered—and they should be so located that any glare will not interfere with ordinary vision.

Ordinarily the maximum amount of light should be given off in a direction about 20 degrees below the horizontal.

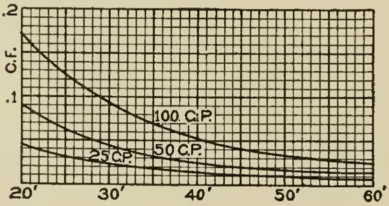


Fig. 54. Illumination Curves for Street Incandescent Lamps

The light should be steady, as flickering is always objectionable.

The light should be well diffused so as to avoid deep shadows.

The light sources should be mounted fairly high and the greater the candle-power of the unit the higher the lamp should be mounted.

Amount of Illumination for Streets. We may consider the amount of illumination considered as essential for the streets in the different sections of a city as follows:

Principal Business Streets. Principal business streets require illumination of from 0.25 to 1.00 foot candle, as uniform as possible; flaming arc lights, luminous arc lights, and incandescent clusters are now in use in the better systems.

Cross Streets and Boulevards. Cross streets and boulevards require from 0.1 to 0.5 foot candles. If they are free from shade trees, arc lights mounted fairly high may be used; if shaded, smaller units in the way of incandescent lamps mounted at a moderate height give much better results.

Residence Street. On residence streets, the illumination should not be high but all crossings should be well illuminated and incandescent systems, spacing lamps about the usual distance between line poles, are ordinarily installed for these streets.

Outlying Districts. In outlying districts the lighting depends upon the amount of money which is to be used for the purpose and it generally takes the form of incandescent units mounted at important points, such as street crossings. No definite rules can be laid down.

General Specifications. In order to determine what type or types of lamps and the number and spacing of each, which will be required for a given or assumed minimum value of illumination, Table XVIII is given. This table was prepared from experimental work by Messrs. Bryant and Hake at the University of Illinois.

Ornamental Street Lighting. Within the last few years the matter of street lighting has received more attention than formerly and the result has been to introduce more ornamental effects in connection with the systems. These ornamental effects take the form of more artistic supports for the light sources; special coloring of the lights; globes and shades designed to make a better appearance by day as well as by night, etc. For the business streets these ornamental systems provide for a brilliant illumination, at least for a few hours in the early evening, and the tendency is toward higher illumination values along the boulevards where the ornamental features are introduced. The more brilliant lighting from the ornamental systems when installed in the business streets has led to the

TABLE XVIII

Horizontal Distribution at Street Surface for Different Heights and Spacings

	Spacing Feet	h Feet	Distance—Feet								
			0	50	100	150	200	250	300	350	400
6.6 Amp. D. C. Enclosed	800	25	.36	.075	.011	.0034	.0014	.0007	.0004	.0004	.0004
	400	25	.36	.075	.011	.04	.003	.004	.011	.075	.36
	200	25	.372	.082	.023	.082	.372	.082	.023	.082	.372
	800	40	.14	.079	.0168	.0054	.0022	.0012	.0007	.0006	.0006
	400	40	.14	.08	.017	.0066	.0044	.0066	.017	.08	.14
	200	40	.142	.085	.034	.085	.142	.085	.034	.085	.142
7.5 Amp. A. C. Enclosed	800	25	.336	.038	.005	.0019	.0008	.0004	.0003	.0002	.0001
	400	25	.336	.038	.0053	.0023	.0016	.0023	.0053	.038	.336
	200	25	.34	.05	.012	.05	.34	.05	.012	.05	.34
	800	40	.132	.05	.0096	.003	.0013	.0006	.0004	.0003	.0002
	400	40	.132	.05	.011	.0035	.0026	.0035	.011	.05	.132
	200	40	.135	.10	.022	.10	.135	.10	.022	.10	.135
6.6 Amp. D. C. Magnetite	800	25	.80	.225	.034	.0111	.0046	.0024	.0013	.001	.001
	400	25	.80	.226	.035	.0135	.0092	.0135	.035	.226	.80
	200	25	.85	.238	.069	.238	.85	.238	.069	.235	.85
	800	40	.315	.205	.047	.0163	.0073	.0039	.0022	.002	.0016
	400	40	.316	.206	.049	.020	.014	.020	.049	.206	.316
	200	40	.329	.225	.096	.225	.329	.225	.096	.225	.329
4.0 Amp. D. C. Magnetite	800	25	.56	.095	.016	.005	.002	.001	.0016	.0006	.0005
	400	25	.56	.095	.016	.006	.004	.006	.016	.095	.56
	200	25	.564	.101	.033	.101	.564	.101	.033	.101	.564
	800	40	.219	.092	.022	.0077	.0033	.0018	.001	.0009	.0008
	400	40	.219	.092	.044	.0095	.0066	.0095	.044	.092	.219
	200	40	.222	.094	.044	.094	.222	.094	.044	.094	.222
9.6 Amp. D. C. Open	800	25	.08	.133	.013	.0035	.0014	.0007	.0004	.0003	.0003
	400	25	.08	.133	.013	.042	.0028	.042	.013	.133	.08
	200	25	.081	.136	.026	.136	.081	.136	.026	.136	.081
	800	40	.031	.185	.026	.006	.002	.001	.0007	.0006	.0005
	400	40	.031	.185	.026	.007	.004	.007	.026	.185	.031
	200	40	.035	.192	.053	.192	.035	.192	.053	.192	.035
Long Burning Flame Vertical	800	25	1.26	.243	.040	.0132	.0059	.0031	.002	.0016	.0014
	400	25	1.26	.244	.042	.0163	.012	.0163	.042	.244	1.26
	200	25	1.27	.261	.084	.261	1.27	.261	.084	.261	1.27
	800	40	.475	.204	.054	.0193	.0085	.0047	.0029	.0023	.0022
	400	40	.476	.206	.057	.024	.017	.024	.057	.206	.476
	200	40	.486	.230	.114	.230	.486	.230	.114	.230	.486
Flame Arc Inclined	800	25	3.81	.265	.034	.010	.004	.002	.001	.001	.001
	400	25	3.81	.266	.035	.012	.008	.012	.035	.266	3.81
	200	25	3.82	.276	.07	.276	3.82	.276	.07	.276	3.82
	800	40	1.49	.32	.055	.0165	.0064	.0032	.0021	.0017	.0016
	400	40	1.49	.32	.057	.0168	.0128	.0168	.057	.32	1.49
	200	40	1.50	.34	.112	.34	1.50	.34	.112	.34	1.50
6.6 Amp. A. C. Enclosed	800	25	.28	.032	.0044	.0016	.0007	.0003			
	400	25	.28	.032	.0044	.0016	.0014	.0016	.0044	.032	.28
	200	25	.28	.035	.009	.035	.28	.035	.009	.035	.28
	800	40	.11	.042	.008	.0024	.0011	.0005	.0003		
	400	40	.11	.042	.008	.003	.0022	.003	.008	.042	.11
	200	40	.11	.045	.016	.045	.11	.045	.016	.045	.11
350 C. P. Tungsten	800	25	.37	.063	.0095	.003	.0012	.0006	.0004	.0002	.0002
	400	25	.37	.032	.01	.004	.0024	.004	.01	.032	.37
	200	25	.37	.038	.025	.038	.37	.038	.025	.038	.37
200 C. P. Tungsten	400	20	.362	.035	.011	.005	.003	.005	.011	.035	.362
	200	20	.365	.04	.023	.04	.365	.04	.023	.04	.365
	d	h	0	25	50	75	100	125	150	175	200
100 C. P. Tungsten	200	20	.181	.078	.015	.0068	.005	.068	.018	.078	.181
	100	20	.183	.084	.034	.084	.183	.084	.034	.084	.183
60 C. P. Tungsten	200	20	.11	.046	.01	.004	.003	.004	.01	.046	.11
	100	20	.11	.052	.021	.052	.11	.052	.021	.052	.11
32 C. P. Tungsten	200	20	.06	.024	.005	.002	.002	.002	.005	.024	.06
	100	20	.09	.028	.010	.028	.06	.028	.010	.028	.06

introduction of the term "White-Way Lighting," but this term applies more specifically to the incandescent lamp systems than to the systems using ornamental arcs.

Ornamental Standards Most Used. A small amount of ornamental lighting is done by means of arches overhanging the streets and studded with small incandescent lamp units, but the effect is not always what is desired and the more common systems use ornamental standards. These standards may be of cast iron; steel pipe with cast-iron fittings; or occasionally bronze for some special standards; and the other extreme, concrete, where the first cost is a considerable item. These supports may be fitted with one or two arc lamps or with incandescent lamps numbering from one to five, the candle-power of the individual units depending upon the amount of illumination and the display desired. For some special effects several highly colored flaming arcs have been mounted upon one standard and, in other instances, units of extremely high candle-power have been mounted very high above the street or the area to be illuminated.

Arrangements for Turning Off Part of Lights. The arc lighting systems are connected to a series system of distribution but the incandescent units in the business districts, where they are placed close together, are more commonly supplied from a constant potential system, either two- or three-wire, and in this case the current is turned on and off automatically by means of a time clock; it may be controlled from the station by special devices; or it may be turned on and off by a patrolman. In systems using clusters of three or five incandescent lamps it is not uncommon to arrange for turning off all but one unit in each cluster after the early hours of the evening and leaving but one unit burning for the remainder of the night.

Since the high-efficiency nitrogen-filled lamp can as yet be obtained only with filaments of a fairly large diameter, units for multiple operation on 110 volts must be of relatively high candle-power. In order to utilize such a high-efficiency lamp in incandescent ornamental street-lighting systems, a few installations have been made using a transformer in the base of the standard transformer which reduces the distribution voltage, which is usually about 110, to a low value suitable for the particular high-efficiency relatively low candle-power unit installed in the fixtures.

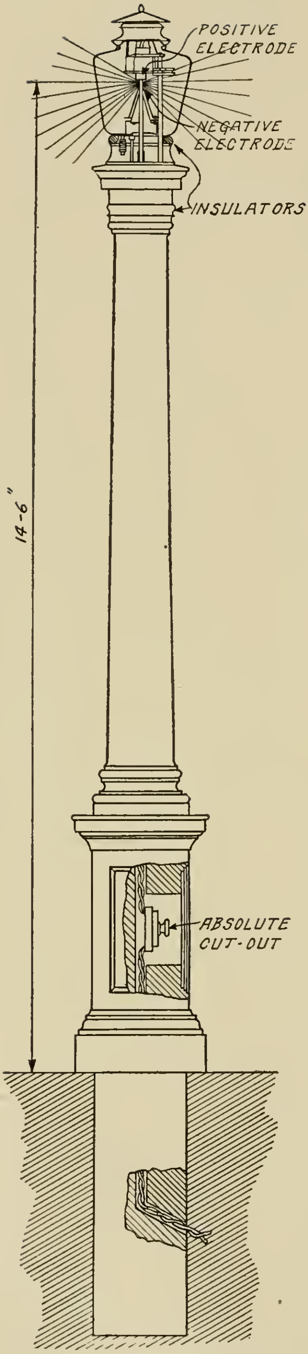


Fig. 55. 6.6-Ampere Luminous Arc Lamp Mounted on Ornamental Pole

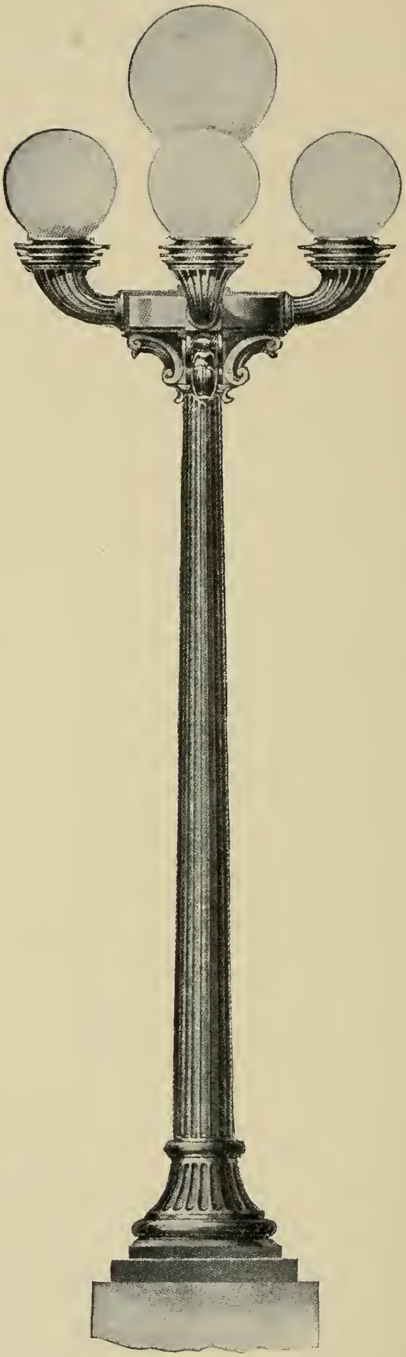


Fig. 56. Ornamental Incandescent Lamp Pole
Courtesy of Smyser-Royer Company

Ornamental street lighting must produce illumination equal to or better than that considered good lighting with the ordinary systems and after that it is a matter of the allowable expense and artistic design as to just what the system will be.

Luminous Arc Specifications. Fig. 55 shows one form of ornamental luminous arc lamp. This lamp and standard is made in more than one size and its use may be outlined as follows: For business streets use a unit of 14 feet 6 inches high, spaced 75 to 100 feet, and staggered, i. e., lamps not placed opposite each other on the street but the unit on one side coming midway between two units on the opposite side. For parkways and boulevards, use a standard 18 feet high unless the foliage interferes. For residence

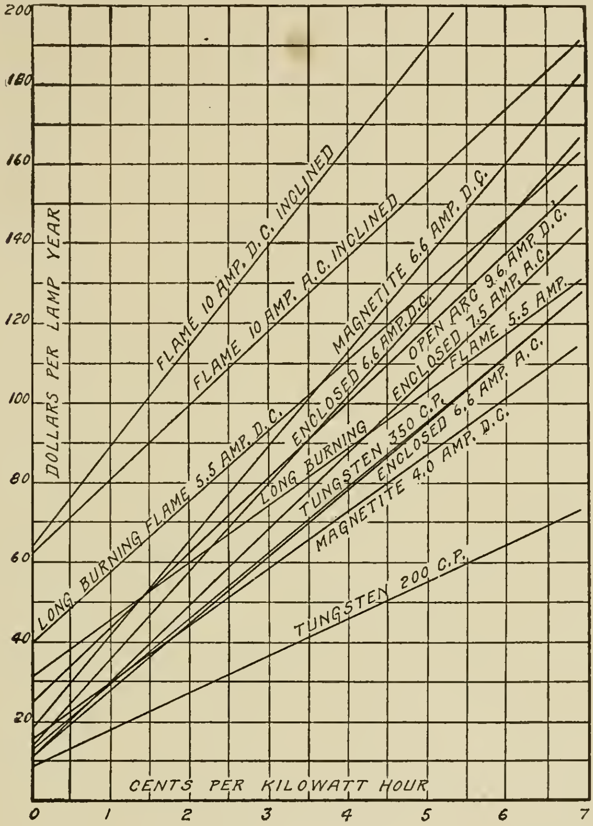


Fig. 57. Curve Showing Annual Operating Cost of Arc Lamps on 4000-Hour Schedule

streets use a unit 12 feet high and space the units about 300 feet apart.

Incandescent Clusters. Fig. 56 illustrates a typical incandescent lamp cluster for business streets. Similar supports may be made for three or for one unit. The clusters are supported from 12 to 15 feet above the curb and with a spacing between standards of from 4 to 6 times the height of the cluster. Standards may be staggered or they may be placed opposite each other on the streets. For a 5-light unit an excellent combination is obtained by using one 100-watt and four 60-watt tungsten lamps per cluster.

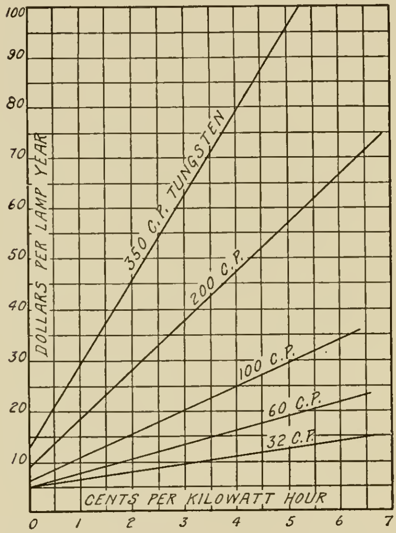


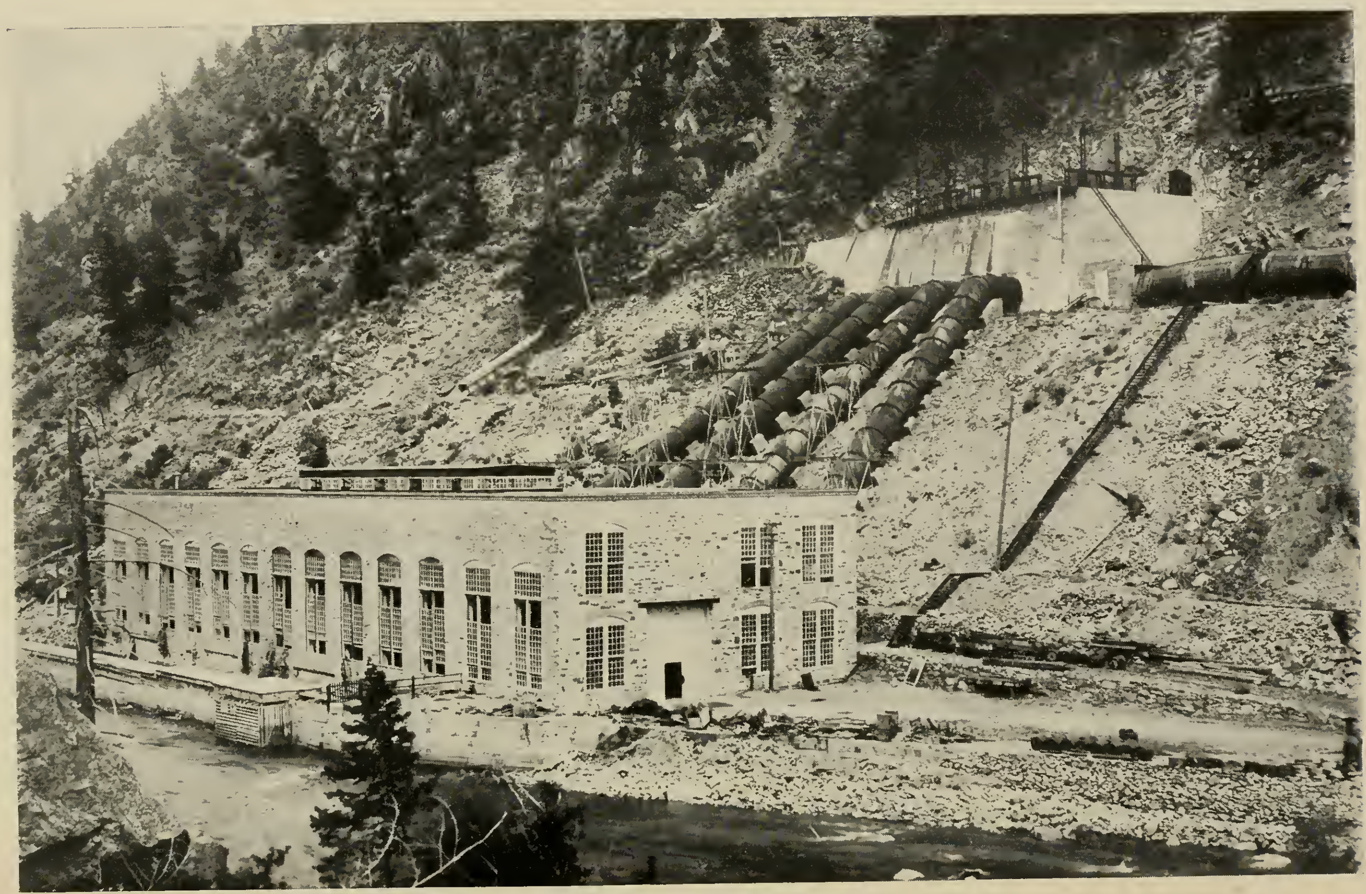
Fig. 58. Curve Showing Annual Operating Cost of Tungsten Lamps on 4000-Hour Schedule

Cost. The cost per standard for incandescent clusters, or for one lamp only, depends upon the material and design of the post, the number and size of the lamp units, the distance they are spaced, etc. For an approximate estimate, the cost of materials only, including cable, regulating devices at the station, etc., will be: five-light pressed-steel standard, total of $96; one-light cast-iron standard, for park service, $44; one-light bracket-fitting, for residence lighting, $15.

Figs. 57 and 58, prepared by Messrs. Bryant and Hake, are on the basis of average cost for labor and materials, interest and depreciation, and for electrical energy at one cent per kilowatt hour.

TRAIN LIGHTING

Of the many specialized fields for electric lighting, probably the lighting of railway cars and trains is as important as any. From about 1850 to about 1875, oil lamps were used almost exclusively for train lighting. From 1875 to 1900 gas occupied the field to the greatest extent. Since 1900 electricity has been introduced more



MADISON RIVER POWER HOUSE NO. 2

Courtesy of Montana Power Company

and more extensively so that now nearly all of the first-class trains and a large proportion of the local passenger trains use some form of electric-lighting outfit. A reduction of the fire risk, the ease of control, the excellent quality of the light, the fact that electric lights do not vitiate the air or heat it to the extent that gas or oil lights do, and the possibility of mounting electric lamps where other types of illuminants could not be used are some of the main reasons for the wide introduction of electric lighting for railway trains. Early electric-lighting outfits were not entirely free from interruptions and gas was necessarily retained for use in cases of emergency. Continued improvement in equipment has been made and at present failures are in the neighborhood of one per 1,000,000 miles of operation.

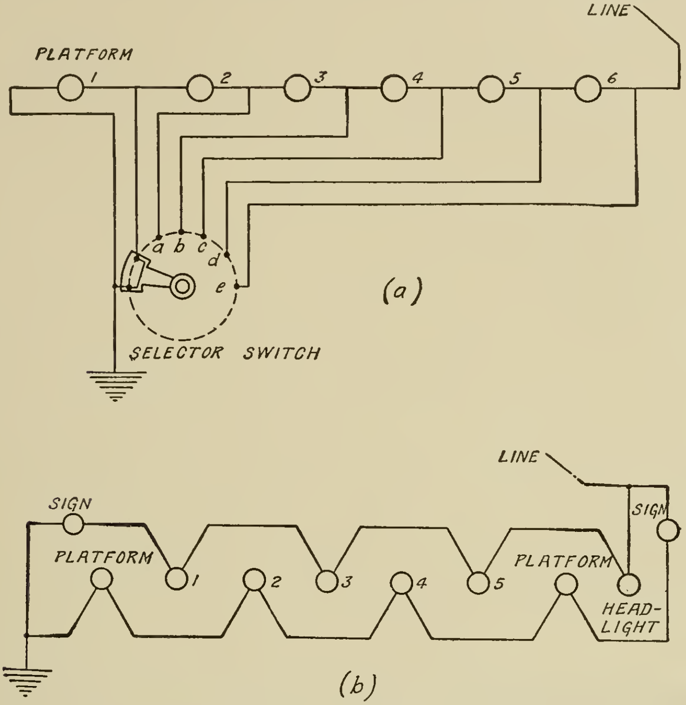


Fig. 59. Wiring Diagrams for Street Car Lamps. (a) For 94-Watt or 56-Watt Tungstens; (b) For Lamps in Two Independent Circuits

Units. The first of the electric car-lighting systems used carbon incandescent lamps which, on account of train vibration and the relatively high voltage then used, had an efficiency of about 4 watts

TABLE XIX

Characteristics of Tungsten-Filament Street-Railway Lamps

Watts	Hor. C. P.	Watts per C. P	Lumens	Life in Hours
23	17.1	1.34	168	2000
36	26.8	1.34	263	2000
56	46.7	1.2	457	2000
94	78.3	1.2	767	2000

per candle-power. With the advent of the higher efficiency incandescent units, each in turn was adapted to train lighting and today the tungsten lamp is standard. The increased efficiency of the lamp has done much to extend the use of electricity for train lighting as the weight and cost of the generating and controlling equipment has been reduced in proportion to the increase in efficiency of the lighting units.

For the lighting of electric cars the units listed in Table XIX are now considered standard. These lamps may be secured for voltages of from 105 to 130, making them adapted, five in series, to line voltages of from 525 to 650. Wiring diagrams for car lighting are shown in Fig. 59.

Table XX gives data covering the present standards for steam train lighting units. The Gem berth-light lamp still has a limited application.

Fixtures and Reflectors. There is considerable leeway in the choice of a suitable fixture and reflector for car lighting; and single-light ceiling fixtures, mounted in one row down the center of the car, single-light ceiling fixtures mounted in two rows, one down either side of the car; and two-light ceiling fixtures, mounted in one row down the center of the car, are all used. Glass reflectors are employed for the majority of the work but metal reflectors are installed in baggage, mail, and express cars, and in other locations where glass reflectors are liable to breakage and appearance is not of first consideration. Semi-indirect units and shades

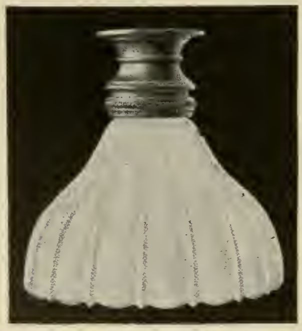


Fig. 60. Typical Electric Car Fixture

TABLE XX

Electric Lamp Units for Steam-Train Lighting

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Mazda	25-34 and 50-65	10	1.23	8.0	79.0	79	8.07	1000
		15	1.23	12.0	79.0	119	8.07	1000
		20	1.23	16.0	79.0	159	8.07	1000
		25	1.23	20.0	79.0	199	8.07	1000
		50	1.23	40.0	79.0	397	8.07	1000

Gem Berth-Light Lamp

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Gem	28-34	15	2.46	6.1	84.5	65	4.32	300
	57-65	20	2.46	8.1	84.5	86	4.32	300

Straight-Side or Compensator Lamps

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Mazda	25-34 and 50-65	10	1.23	8.0	79.0	79	8.07	1000
		15	1.23	12.0	79.0	119	8.07	1000
		20	1.23	16.0	79.0	159	8.07	1000
		25	1.23	20.0	79.0	199	8.07	1000
		40	1.23	32.0	79.0	318	8.07	1000
		50	1.23	40.0	79.0	397	8.07	1000

with special ornamental features are also used. Two things must be considered in selecting fixtures for car lighting: Glare must be reduced to a minimum on account of the comfort of the passengers, and hence bare lamps cannot be used to advantage; and the efficiency of the system is of importance, especially on account of the equipment which must be carried. Because of the necessity of mounting the units relatively low, special precautions are necessary to prevent glare, and the deep bowl type or the indirect type of reflectors are effective in this respect. Fig. 60 illustrates a modern electric car fixture which, when used with 94-watt tungsten lamps and spaced 8 feet and 10 inches apart in a row along the center of the car, gave average illumination at the seats on a plane 37 inches above the floor of 3.72 and 4.32 foot candles at the positions ordinarily occupied by passengers.

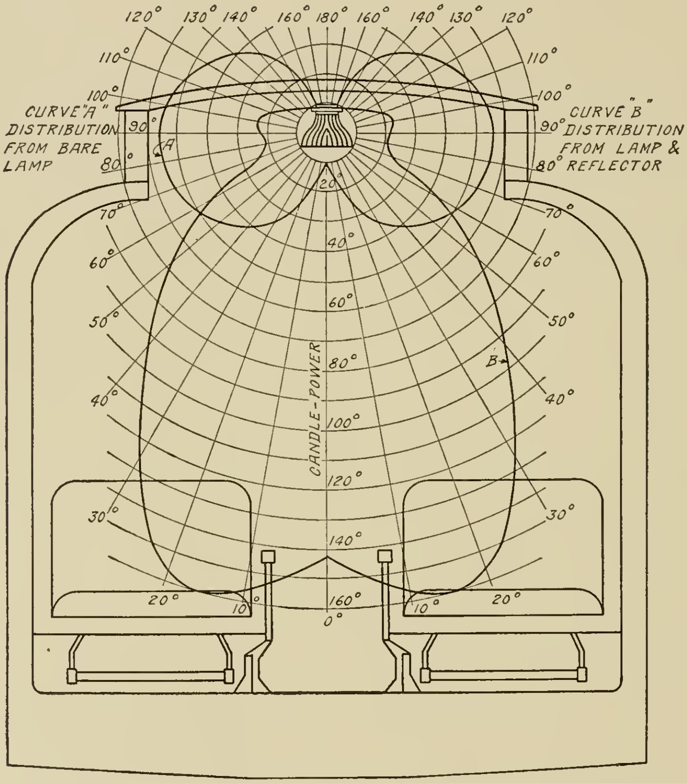


Fig. 61. Distribution Curves Showing Effect of 40-Watt Clear Prismatic Reflector on Light Distribution from 56-Watt Railway Tungsten Lamp

Fig. 61 shows the effect of a suitable reflector for car lighting upon the distribution curve of the bare lamp.

As illustrative of the illumination of steel passenger coaches, the results of a test upon a standard car equipped with 10 single-light center-deck fixtures, each fixture fitted with a 50-watt 60-volt lamp and a deep bowl-shaped clear prismatic reflector, showed an average of 2.6 foot candles at points over the seats and 36 inches above the floor.

Headlights. For headlights on electric cars and locomotives the luminous arc light is used to a considerable extent. This is ordinarily made in 4-ampere and 2-ampere sizes. For street cars there are two methods of producing a dimmer headlight for use on the brightly lighted streets; one is to equip the lamp case with an incandescent lamp, switched on in place of the arc, and the other is to reverse the current through the arc; the light is considerably dimmed by sending the current in the reverse direction. With the development of the helical shape of tungsten filament, incandescent lamps are being used to a greater extent where a powerful headlight is needed. The supply of electricity for electric arc lights for steam locomotives is from a small steam-driven generator mounted on the locomotive.

GENERATOR SYSTEMS FOR TRAIN LIGHTING EQUIPMENT

The results of all of the preliminary experimental work have been to establish three general systems for the supply of electricity for train lighting. These are known as: the straight storage-battery system; the head-end generator system; the axle-generator system.

Straight Storage-Battery System. In the straight storage-battery system, batteries are provided and they must be charged at the terminals. Either the cars must be held over while the batteries are being charged or else there must be provision for the interchange of batteries. For such systems the batteries must have a capacity in excess of the amount of electricity required for the regular run of the cars equipped and suitable charging and exchange stations must be provided. The batteries in general service are rated at about 300 ampere hours and, as ordinarily mounted, the battery is divided into two parts, each part giving 32 volts, the two parts in series furnishing 64 volts. An ampere-hour meter is used as an indication of the state of charge of the battery. Occasionally, such a battery will be operated with its two parts in parallel at 32 volts but standard practice uses the series connection. The batteries are mounted in boxes underneath the car where they are readily accessible for exchange or inspection, and charging plugs are provided for facilitating connections when they are charged at the terminals. The wiring for the lamps is exceedingly simple, the straight parallel connection of the lamps being used. The main advantage of the straight storage-battery system of train lighting is its great simplicity.

Head-End Generator System. For the head-end generator systems, a steam generator, usually driven by a steam turbine, is mounted either in the baggage car or on the locomotive. The steam turbine is supplied with steam from the locomotive boiler at reduced pressure through a flexible steam hose connection and electrical conductors are run throughout the length of the train for the supply of electricity to the lights. Flexible connectors are in use between

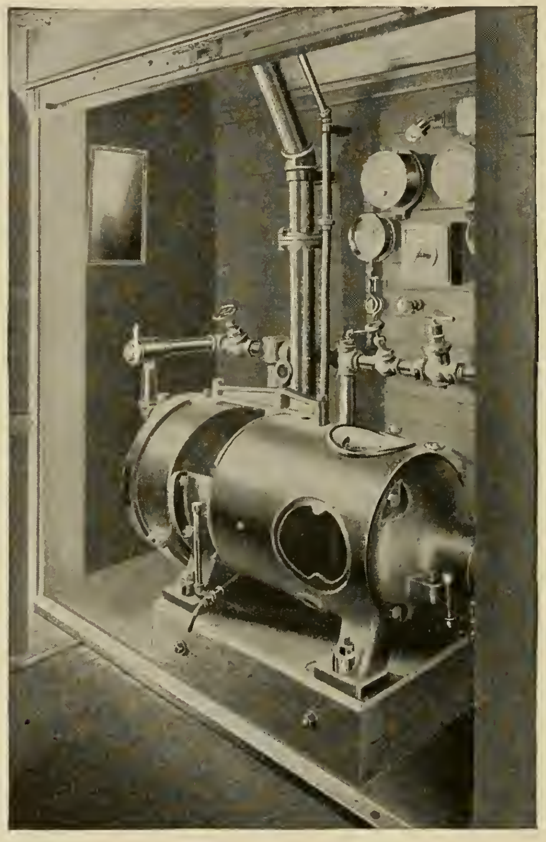


Fig. 62. Steam-Driven Railway Generator Equipment Located in Baggage Car
Courtesy of General Electric Company

cars. Since the cars cannot always be connected to the locomotive or to the baggage car upon which a generator is in operation, a storage battery is still an essential item of the equipment.

Equipment. In general, a head-end generator system requires: a generator, usually steam-turbine-driven, as engine-driven generators produce some vibration (this may be placed in the baggage car or on the locomotive); the necessary indicating and controlling apparatus, placed near the generator; proper train lines and flexible connectors; switches; storage batteries, usually put up in two sections, which sections are mounted underneath the car and connected in series; and some device for maintaining a proper voltage at the lamps. The usual voltage of the system is 64, the same as the straight storage-battery system. It has the disadvantage of not being very flexible and its main application is to through trains which regularly are made up with the same equipment, and this equipment carried for long runs. Taking the equipment up in the same order as enumerated above, the generator is usually of a capacity from 15 to 35 kilowatts, the turbine operating at a steam pressure of 90 to 100 pounds, non-condensing, and the generator rated at 80 volts for the 64-volt system. Fig. 62 illustrates such a generator in position. The usual ammeter, voltmeter, field rheostat, and main switch are supplied in connection with the generator. The usual train line is of 3-0 conductors with flexible connections between cars; and these connections are made so that a reversed polarity on the batteries is not possible.

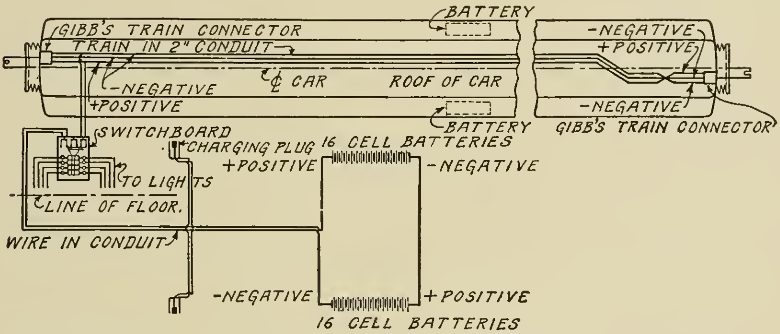


Fig. 63. Diagram of Standard Train Line and Battery Connections as Recommended by the Association of Railway Electrical Engineers

Standard Car-Wiring Diagrams. Fig. 63 shows a standard car-wiring diagram. A few batteries of 300 ampere-hours capacity may be installed, say three for the whole train, or each car may be equipped with a smaller battery. These batteries do not differ, except possibly in size, from those used with the straight storage-battery system. On some systems no special regulating devices for the control of the voltage on the lamps is installed, and in such cases the lamp voltage is, at times, considerably above normal. When operating the generator at 73 volts, the voltage at the rear car of a seven-car train will be about 66 volts and at times it is desirable to run the generator at 78 volts in order to charge the batteries properly. The better systems use some form of controlling device, of which there are several available. With these the generators may be operated at the voltage required by the batteries and the lamps still be operated at their normal voltage of 63. Some of these regulators operate upon the same principle as the regulators which will be described later in connection with the axle-generator systems, while in other cases special boosters are installed. Fig. 64 shows a wiring diagram of a system used by the Baltimore and Ohio Railroad, which system has a lamp regulator on each car. Fig. 65 shows the wiring of one type of booster system. Each car is equipped with a motor generator or booster set and a control box for this regulator, both mounted underneath the car. The booster armature is connected in series

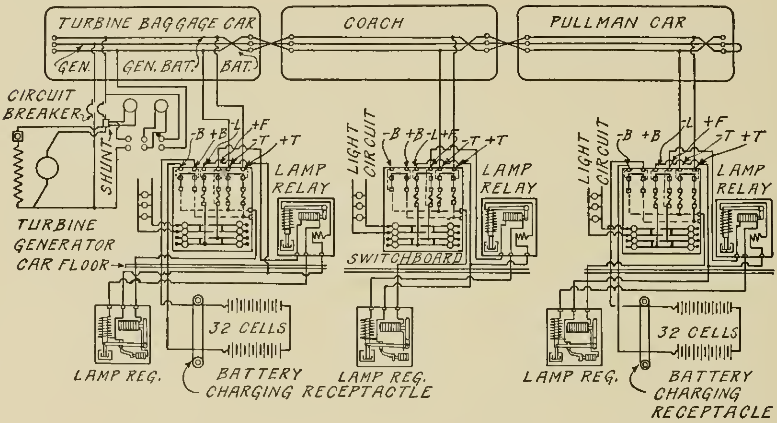


Fig. 64. Wiring Diagram for Baltimore and Ohio Head-End System

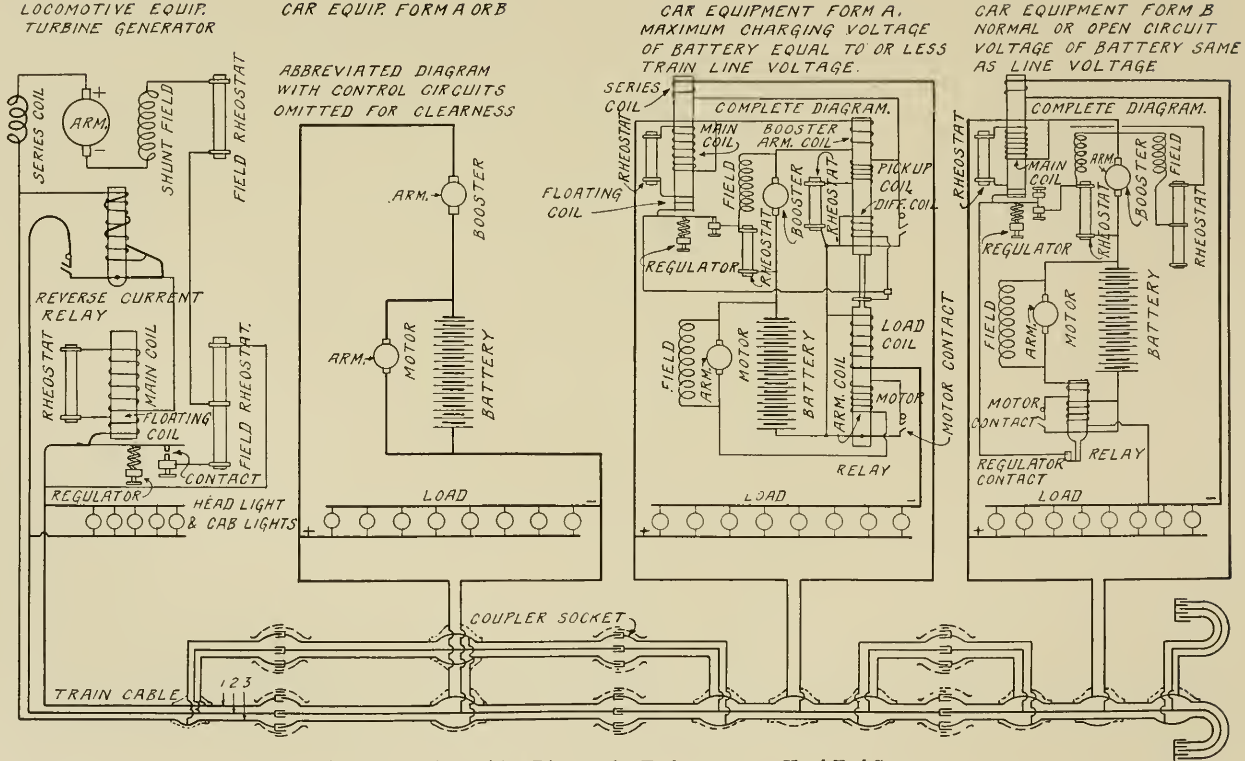


Fig. 65. Typical Wiring Diagram for Turbo-generator Head-End System

with the battery, and the lamps, for all practical purposes, are connected across the train lines. Two forms of regulator are manufactured: Form A, for use when the maximum charging voltage of the battery is equal to or less than the train line voltage, and Form B for use when the open-circuit voltage of the battery is equal to the train line voltage. The action of the regulators is such that, when the train-lighting load is heavy, the battery voltage is lowered, so that it will discharge and help the generator and, when the lamp load is light, the battery voltage will be raised and the battery will be charged.

Axle-Generator System. *Equipment.* The axle-generator system is very commonly employed and this system requires the following general equipment: an axle-driven generator mounted on the trucks with a suitable suspension from the truck frames; a driving mechanism between the generator armature and the axle; a regulator for controlling the voltage and output of the generator, at all train speeds; an automatic switch designed to keep the battery from discharging through the generator; a regulator for controlling the voltage at the lamps; and a battery for supplying the current when the generator is not in use.

Requirements. For an axle-generator system to be successful it should meet the following requirements: The polarity of the generator must remain unchanged with a reversal of the direction of the motion of the car; at all train speeds from the time of the cutting in of the generator to the maximum, the voltage and output of the generator must be kept within practical limits; the generator must be automatically cut in and out of service as the speed of the train rises above or falls below a certain critical value; the transfer of the lights from the battery to the generator and *vice versa* must be accomplished without serious voltage changes on the lamps; the voltage upon the lamps must, at all times, be kept within such limits that the illumination will be satisfactory and the life of the lamps will be reasonable.

In order to accomplish the above, several different systems have been worked out and the essential parts of some of the systems will be considered briefly here:

Mounting of Generator. The general practice is to support the axle generator from the truck frame. "Inside" suspension, i. e., mounting the generator between the axle and the truck-end sill, was first employed but "outside" suspension, placing the generator outside of the truck frames, is preferred on account of the greater accessibility. Of the bottom-pivoted, top-pivoted, parallel-link, and sliding methods of suspending the generator from the suspension framing, the parallel-link method is preferred.

Drive for Generator. The usual drive is by means of a rubber-filled canvas belt running on steel pulleys on the axle and on the generator shaft. A suitable belt tension is provided by means of springs which provide relief to the belt, when this is required on account of the movement of the car axle with respect to the truck frame. Ball bearings are used on some generators.

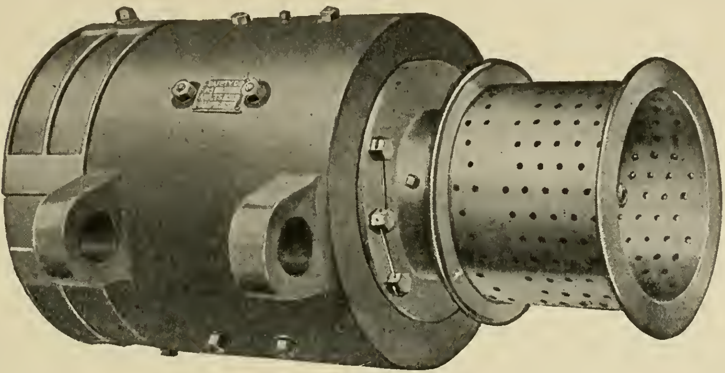


Fig. 66. Belted Train-Lighting Axle Generator
Courtesy of Safety Car Heating and Lighting Company

Generators. Straight shunt-wound generators of the two-pole or multipolar type are in general use but in some of the systems employed abroad a special generator, designed to maintain automatically a constant current irrespective of the speed, is used. The Rosenberg dynamo, designed especially for train lighting, is one type of such a generator but, since its use in the United States is rather limited, it will not be described here. The generator capacity varies from 2 to 4 kilowatts, depending upon the type of car and its lighting arrangements. The usual method of operation is to keep the current output of the generator approximately constant, the battery furnishing the excess energy required when all lamps are burning and the generator charging the battery when the lamp load is not so heavy. Fig. 66 illustrates a train-lighting axle dynamo as made by the Safety Car Heating and Lighting Company.

Reversal of Polarity. In order that the generator may operate with the same polarity upon the train and battery line at all times, it is necessary in most cases that a device for reversing the polarity of the machine with the reverse direction of the motion of the car be provided. Two general schemes are in use: In one, some mechanical device is provided to close a double-throw reversing switch to the proper position; and in the other, the brushes are rotated through 90 electrical degrees, either by the force of friction between the commutator and the brushes or by some other mechanical means.

Automatic Switch. In order that the generator shall be brought into action when the car has reached a certain predetermined speed and that it shall be disconnected from the system and the lamps supplied from the battery alone when the speed falls below this value, some form of automatic switch is required and such a switch may be operated electrically or mechanically. The electrical operation of this switch is preferred.

Generator Regulator. If the generator is to be operated at constant current, irrespective of its speed and irrespective of the lighting load, some regulating device must be used to accomplish this. Many methods are in use and among them may be mentioned: automatic slipping of the belt, the sliding of the armature along the generator shaft, counter compounding, special boosters, armature reaction, and automatic rheostats. Automatic field rheostats appear to be preferred in the American practice. Ordinarily the generator operates at constant-current output but, as the battery charges when the lamp load is light, the generator voltage will have to increase gradually in order to maintain a constant output and, if this were continued indefinitely, the batteries might become badly overcharged. Another function of the control device, then, is to reduce the current output of the generator, after the batteries are fully charged, so that the generator will "float" upon the train line.

Lamp Regulator. If the generator voltage is going to vary some 30 per cent, as is necessary if it is to provide for the proper charging of the battery, then some mechanism is necessary for maintaining a constant voltage on the lamps and this regulator usually consists of a resistance which is automatically switched in and out of the lamp circuit as may be required, Fig. 67. The usual lamp voltage for the axle-generator system is 32.

Operation of Safety Car Lighting and Heating Company Equipment. With all of the necessary devices it is readily seen that there are many different arrangements of the details in use in making up a complete train-lighting system and individual manufacturers put out several different types of equipment adapted to the various needs of the different roads and the different train equipment. To describe all of them would require a very great amount of space, so that details of only one system, the one employing the Type F regulator as manufactured by the Safety Car Lighting and Heating Company, will be given here. Fig. 68 shows the connections of the system and its operation is as follows:

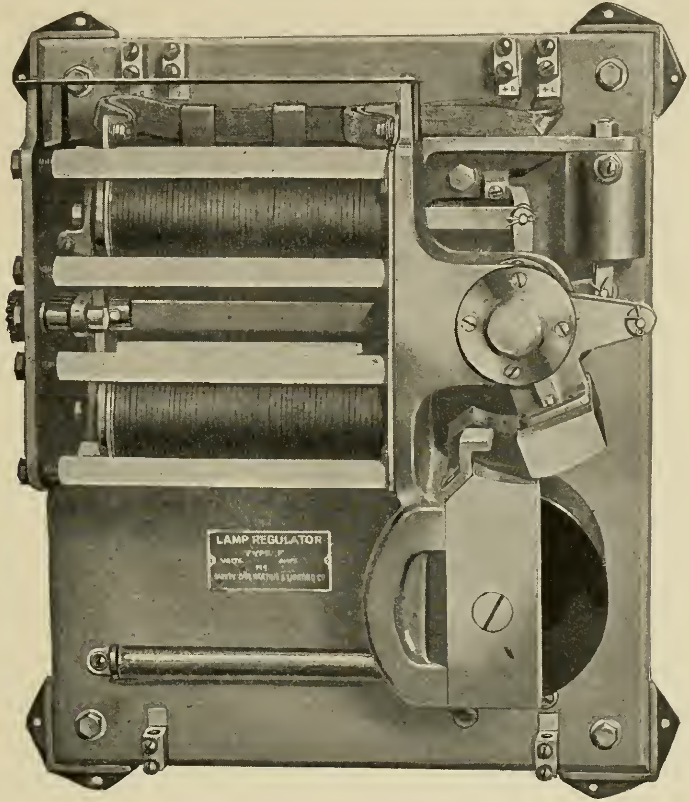


Fig. 67. "Type F" Lamp Regulator Panel
Courtesy of Safety Car Heating and Lighting Company

When the dynamo is at rest the field resistance carbons C are tightly compressed by the pull of the spring G_1 so that their resistance is low. As soon as the armature begins to revolve, current flows through the field F and builds up a voltage which energizes the lifting coil of the main switch H. As soon as this voltage is the same as the battery voltage, the main switch closes, cutting into circuit the series coil of the main switch, which holds the switch firmly closed. Current now flows from the positive dynamo terminal, through the series coil of the main switch H, through the series regulating coil S to the lamps and storage battery B, and back to the negative dynamo terminal.

As the train speed increases and the dynamo is able to give its full output, the control is by means of the series coil S, provided the full output of the dynamo can be used for charging the storage battery or for the lamps. As the storage battery becomes charged and its voltage rises, the current tapers off so that the full output of the dynamo is no longer required, and the series coil arm moves out of engagement with the voltage coil arm and rests against its stop. The voltage coil A then prevents the voltage from rising above the voltage for which the regulator is set.

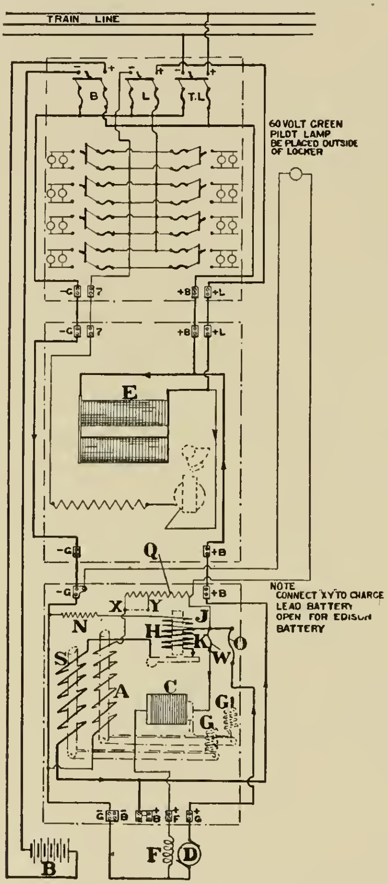

TRAIN LINE
B
L
T.L
60 VOLT GREEN PILOT LAMP BE PLACED OUTSIDE OF LOCKER
-G
7
+B
+L
E
Q
NOTE CONNECT XY TO CHARGE LEAD BATTERY OPEN FOR EDISON BATTERY
X
Y
J
N
H
K
O
S
W
A
C
G1
G
F
D
B

Fig. 68. Wiring Diagram for Lamp Regulator in Car

Courtesy of Safety Car Heating and Lighting Company

If a lead battery is charged at a constant voltage of 2.5 per cell, the charge will start at a high rate and automatically taper to nearly zero as the battery becomes full, corresponding to a stop charge.

In a 30-volt equipment having sixteen cells, the battery will be protected from overcharge if the dynamo gives 40 volts and the battery will be charged in the shortest possible time. If, however, the battery is almost discharged and there is a heavy lamp load, the demand on the dynamo would be greater than its safe capacity, so that coil *S* is necessary to limit the current the dynamo can give. The action of the Type "F" dynamo regulator is, therefore, to cause the dynamo to give its full rated capacity at all times if it can be used, and to protect the battery from overcharge as its voltage can never be above 2.5 volts per cell.

The lamp regulator keeps the voltage constant at the lamps by varying in the proper amount the carbon resistance *E*, in series with the lamps. The carbons *E* are compressed by an adjustable spring connected to a link acting through a toggle. The pull of the spring is opposed by the pull of the electromagnet which is connected directly across the lamp mains and is so designed that the armature will stay in any position throughout its stroke when the lamp voltage is right.

When the lamp voltage is high, the magnet becomes stronger and pulls the armature down against the pull of the spring and reduces the pressure upon the carbons *E*, increasing their resistance and bringing the lamp voltage back to normal. If the lamp voltage is low, the magnet becomes weakened and the spring pulls the armature back and, through the toggle, exerts enough pressure on the carbon discs to decrease their resistance and bring the lamp voltage back to normal.

Data Covering Various Types of Equipment. Table XXI gives some comparative data covering the various makes of train-lighting equipment.

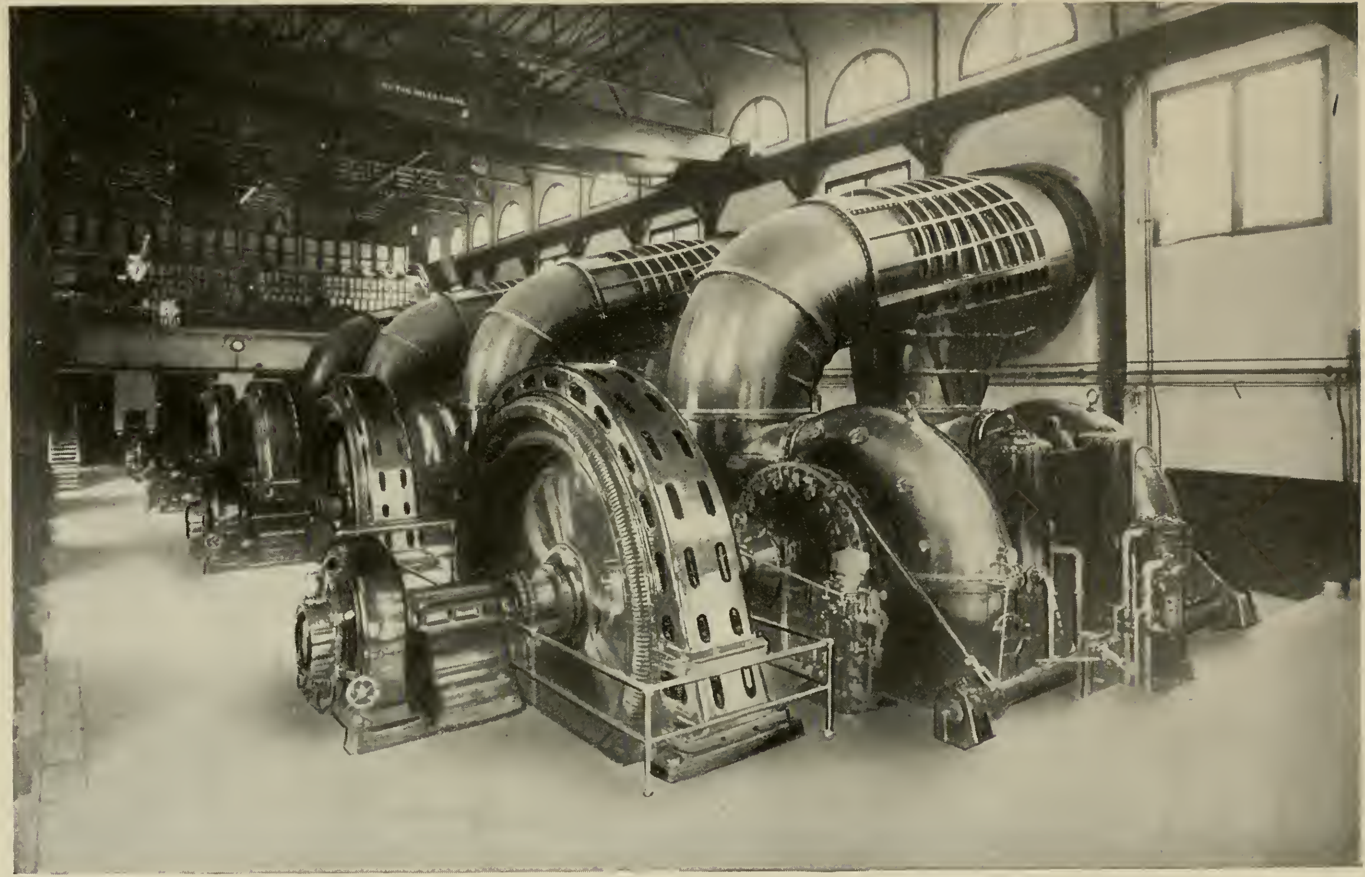
SHADES AND REFLECTORS

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

TABLE XXI

Comparative Data of Various Makes of Electric Train-Lighting Equipment

Makers	Single-or Double-Battery System	Method of Transposing Batteries in Double System	Type Constant Current or Constant Voltage	Pole-Changing Device	Method of Regulation	Method of Adjusting Output	Type of Automatic Switchgear	Voltage Compensation in Lamp Circuit when Charging	Alteration of Compensation when Lamps are Switched	Alteration to Output when Main Lamp Switch is Operated	Overcharge Preventer (Type)
J. Stone & Co.	Double	On reversal of rotation (mechanical)	Constant current	Switch arm governor-operated	Slipping belt	Belt tension	Mechanical	Second battery	None	None	None
Leeds Forge Co.	Single	....	Constant current	Brush rocker	Cam slides armature	Spring collar adjusting nut	Electrical	Lamps across fewer cells	Self-compensating	None	Breaks field current
Mather & Platt	Double	By hand switch	Constant current	None required	Armature reaction	Field resistance	Electrical	Second battery	None	By field resistance	Adds field resistance
Vicars, Ltd.	Single	....	Constant current	Brush rocker	Automatic rheostat	Diverter	Electrical	Automatic rheostat	Automatic rheostat	Diverter has some effect	Switches extra shunt coil to main a to rheostat
Tudor Co.	Single	....	Constant current	Brush rocker	Counter compounding	Diverter	Electrical	Hot iron-wire resistances	Separate wire resistance	By field resistance	Adds extra field resistance
Silvertown	Double	Mechanical	Constant current	Governor-operated	Counter compounding	Diverter	Mechanical	Second battery	None	None	None
Brown-Boveri	Single	....	Rising voltage if lamps not on	Brush rocker	Voltage regulator	Adjustment of regulator	Electrical	Fixed resistance	Regulator alters dynamo volts	Regulator alters dynamo volts	Adds resistance in regulator circuit
Dalziel	Single	....	Constant voltage	None required	Differential exciter	Rheostat	Electrical and mechanical	Resistances	Each lamp or group of lamps on separate resistance	Battery charging independent	None required



ONE 6125-K.W. AND THREE 5000-K.W. 4000-VOLT GENERATORS, LITTLE FALLS STATION, WASHINGTON WATER POWER COMPANY

Courtesy of General Electric Company

TABLE XXI (Continued)

Comparative Data of Various Makes of Electric Train-Lighting Equipment

Makers	Single-or Double-Battery System	Method of Transposing Batteries in Double System	Type Constant Current or Constant Voltage	Pole-Changing Device	Method of Regulation	Method of Adjusting Output	Type of Automatic Switchgear	Voltage Compensation in Lamp Circuit when Charging	Alteration of Compensation when Lamps are Switched	Alteration to Output when Main Lamp Switch is Operated	Overcharge Preventer (Type)
Grob.......	Double	Mechanical	Constant voltage	Mechanical	Series excitation armature bucking against regulating battery	....	Mechanical	Lamps on dynamo; battery on booster	None required	Battery charging independent	None required
Buttner....	Single	....	Constant current	None required	Armature reaction	Field resistance	Electrical	Hot wire resistance	Separate hot wire resistance	By field resistance	Adds extra field resistance
Newbold...	Single	....	Constant current	Mechanical	Automatic rheostat	....	Electrical	Resistances	Separate resistance	By extra coil on regulator	....
Gould......	Single	....	Compound	Mechanical	Carbon powder regulator. Series and shunt	....	Electrical	Separate regulator	Separate regulator	....	Shunt coil of regulator
Consolidated	Single	....	Constant current	Mechanical	Automatic rheostat	Adjustment of regulator	Electrical	Automatic resistance	Automatic resistance	None	Adds field resistance
United States	Single	....	Constant current	Brush rocker	Automatic rheostat	Adjustment of regulator	Electrical	Automatic rheostat	Automatic resistance	None	Reduces dynamo voltage
Safety	Single	....	Constant Current	Brush rocker	Automatic rheostat	Adjustment of regulator	Electrical	Automatic rheostat	Automatic rheostat	None	Reduces dynamo output

TABLE XXII

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Opal glass	32.2
Opaline glass	23

A considerable amount of light is absorbed by the material used for the construction of shades. Table XXII shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

Frosted Globes. One of the simplest methods of shading incandescent lamps is by the use of frosted bulbs. These serve to reduce the intrinsic brightness of the lamp and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in Fig. 69, is an example of such a combined shade and reflector. Opal or opalescent enclosing globes are often used for reducing the intrinsic bril liancy and diffusing the light.

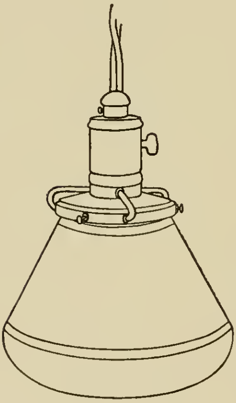


Fig. 69. McCreary Shade

Holophane Globes. Holophane globes are made for both reflecting and diffusing the light and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves that form surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep rounded vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen and the globe appears as if made of some semi-transparent material. The holophane glassware is made in a large variety of artistic designs and for all types of incandescent lamps. By the proper selection of a reflector, the distribution of the light of the unit used may be made that which is best suited to the particular case of lighting in hand. Figs. 14 and 15 give some idea of what can be accomplished by these shades.

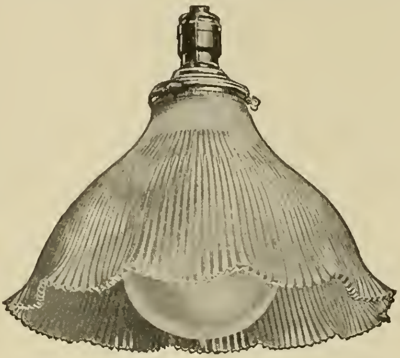


Fig. 70. Typical Prismatic Reflector
Courtesy of National Electric Lamp Association

Changes have been made in the original design of the holophane reflector and the modern type is generally known under the term, "prismatic reflector". The appearance of the prismatic glass reflector is shown in Fig. 70 and for the tungsten lamp it is regularly made in three types: extensive, where the light is widely distributed below the horizontal plane; intensive, where the light is more concentrated in the downward direction but still fairly well distributed; and focusing, where nearly all of the light is thrown directly downward from the lamp. Fig. 71 well illustrates the character of the distribution when these reflectors are used. Clear glass reflectors are very effective if they are properly designed and carefully selected.

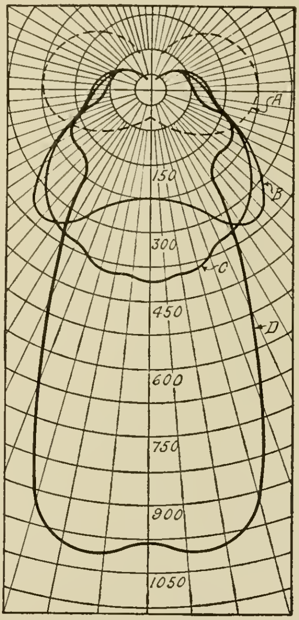
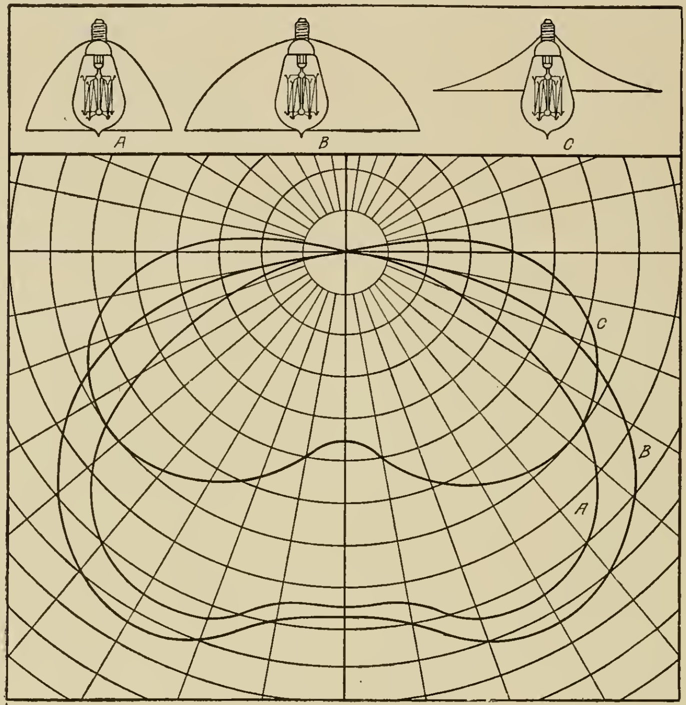


Fig. 71. Photometric Curves for Prismatic Reflectors. *A*-Bowl Frosted Tungsten Lamp; *B*-Same Lamp with Extensive Type Reflector; *C*-Same Lamp with Intensive Reflector; *D*-Same Lamp with Focusing Type Reflector

Metal Reflectors. Glass reflectors are subject to breakage and this is to their disadvantage in certain locations. Metal reflectors have been designed for use where the unit must be more rugged. Metal reflectors may be lined with porcelain enamel, or a bright metallic surface, such as can be secured with the use of aluminum, may be employed for the reflecting medium. Fig. 72 illustrates both the form of these units and the distribution of light from them.



Percentage Light Flux

Unit	A	B	C
Total light from lamp	100.0	100.0	100.0
Light absorbed by reflector	37.0	18.6	14.8
Light in upper hemisphere	0.0	0.0	6.4
Light in lower hemisphere	63.0	81.4	78.8
Light in 60° zone	53.4	59.2	41.3

Fig. 72. Types of Metal Shades and Characteristic Distribution Curves

Decorative Shades. Where more decorative effects are desired light white or opalescent glass is being used to good advantage. Much more attention is being paid to the design of the shades and to the quality of the glass used and the result of this study is the production of shades which, while they are ornamental, at the same time are also very efficient. Fig. 73 shows one of many lines of these shades and Fig. 74 is characteristic of the distribution curves obtained.

Reflectors for Indirect and Semi-Indirect Lighting. Reflectors for indirect lighting are often made a part of the construction of the building, as in "cove" lighting, but totally indirect lighting fixtures are available and Fig. 75 shows one such unit. Semi-indirect fixtures are, as a rule, rather less efficient than indirect as in the former case the bowls must be of opalescent glass and the absence of the reflector cuts down materially the amount of light reflected to the ceiling. Figs. 76 and 77 show an indirect fixture with a small diffusing globe at its base which illuminates the opalescent bowl below the reflector. This gives an efficient indirect illumination and at the same time provides the more artistic semi-indirect effect.

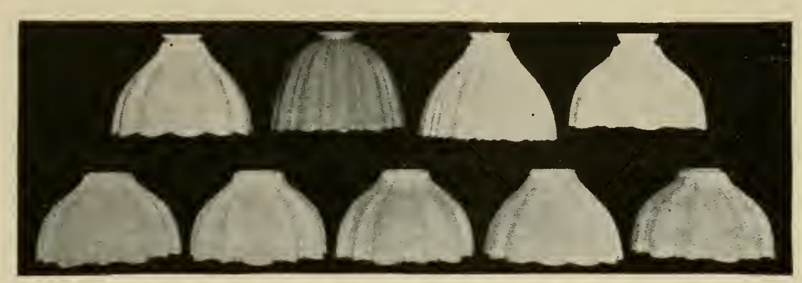


Fig. 73. Typical Decorative Shades for Incandescent Lighting

Incandescent Street Lighting. For incandescent street lighting where the system is ornamental and the lamps are mounted in clusters, opal enclosing globes are used; but in other installations a reflector, designed to give the best distribution of light for street illumination, is utilized. Fig. 78 shows a "radial wave" reflector and Fig. 79 illustrates the effect of this, and one other type of reflector, upon the distribution of light.

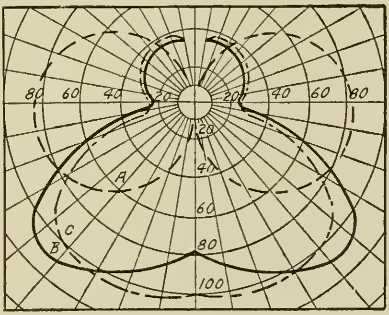


Fig. 74. Characteristic Distribution Curves for Reflectors Shown in Fig. 73.

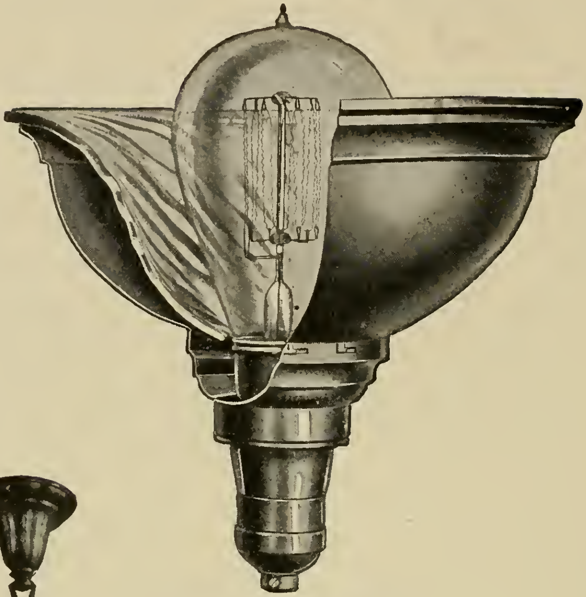


Fig. 75. Indirect Lighting Fixture with Part Cut Away to Show Position of Reflector

Courtesy of National X-Ray Reflector Company

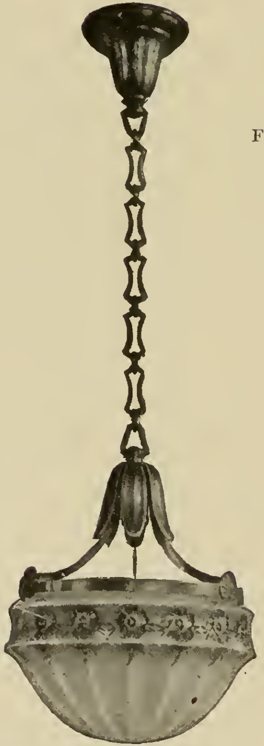


Fig. 76. Indirect Ceiling Fixture with Semi-Indirect Effect

Courtesy of National X-Ray Reflector Company

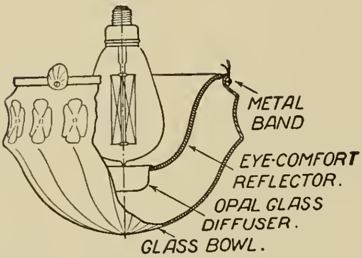


Fig. 77. Diagram Showing Method of Getting Semi-Indirect Effect by Use of Extra Diffusing Shade

Courtesy of National X-Ray Reflector Company

The possibilities in the way of shades and reflectors, both from the utilitarian and ornamental standpoint, are very great and a wide variety of models are now manufactured as standard.

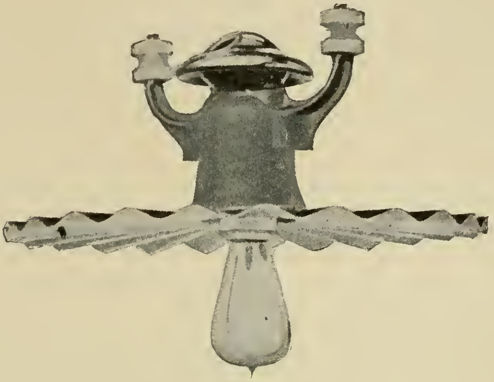


Fig. 78. Center Span Strain Insulator Suspension Fixture
Courtesy of General Electric Company

Special fixtures for the large lighting units, such as the various types of arc lights, are now available. Fig. 80 shows an enclosed arc lamp fitted with a shade and a concentric diffuser. The effect of this combination is best shown in Fig. 81. Fig. 82 shows the change in the illumination curve produced by such shading. Inverted arcs have some application where the light may be readily reflected and

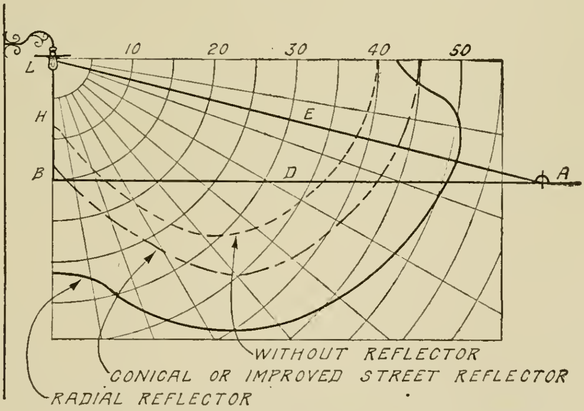


Fig. 79. Distribution Curves for Tungsten Lamp with Different Types of Reflectors

TABLE XXIII

Opal enclosing and clear outer	100 per cent
Clear enclosing and clear outer	91.2 per cent
Clear enclosing and opal outer	85.1 per cent
Opal enclosing and opal outer	82.7 per cent

diffused as in lighting large rooms with light finish. Reflectors of this general type are now being manufactured in such a form that they may be built in and become part of the ceiling of the room to be illuminated.

Opal Enclosing Globes. The use of opal enclosing globes is often recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table XXIII gives the efficiency of different globe combinations for street lighting, assuming the opal inner and the clear outer globes as 100 per cent.

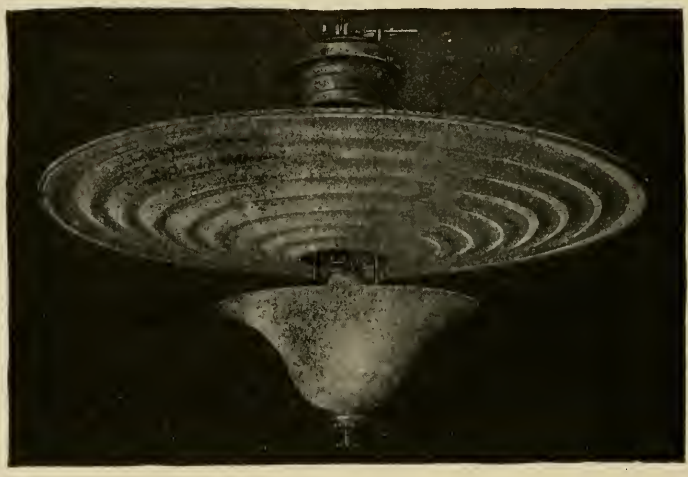


Fig. 80. Enclosed Arc Lamp Fitted with Shade and Concentric Diffuser

PHOTOMETRY

Photometry is the art of comparing the illuminating properties of light sources and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of

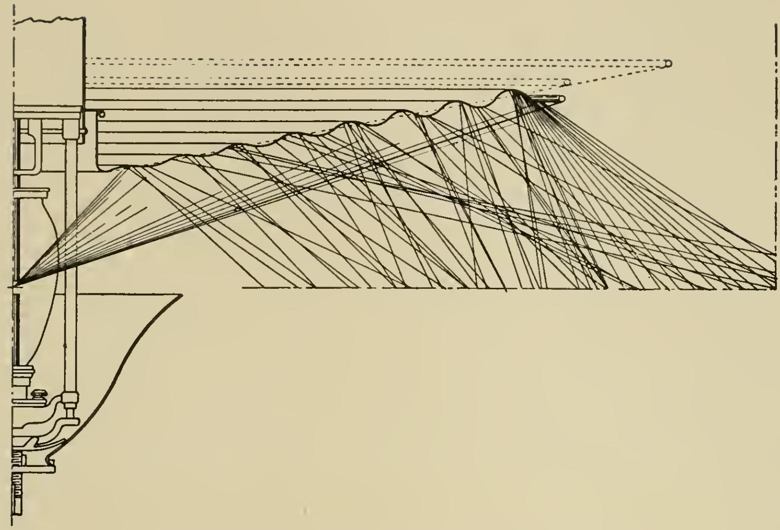


Fig. 81. Diagram Showing Effect of the Concentric Diffuser

different types of lamps as sources of illumination, together with their efficiency; also, by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

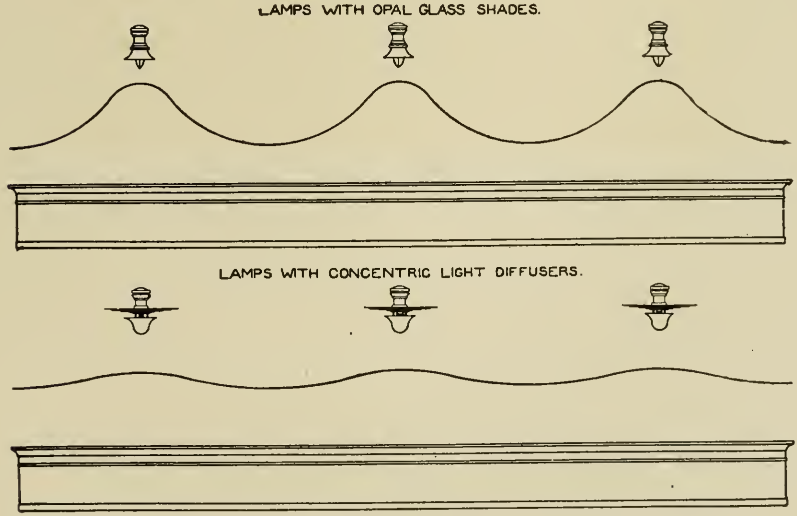

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 82. Illumination Curves for Lamps with and without Light Diffusers

LIGHT STANDARDS

Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the *candle-power* and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is 10 inches, its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and the spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grams per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least 15 minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—10 to 15 minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays, and the composition of the spermaceti is more or less uncertain.

German Candle. The German candle is made of very pure paraffine, burns with a normal flame height of 50 millimeters, and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

TABLE XXIV

Photometric Units

Bureau of Standards Unit, United States	1.000
Reichsanstalt Unit, Germany	0.998 × 0.88
National Physical Laboratory Unit, England	0.984
Laboratoire Central Unit, France	0.982

	CARCEL	HEFNER	VERNON-HARCOURT
Carcel	1.00	10.75	0.980
Hefner	0.0930	1.00	0.0915
Vernon-Harcourt (pentane)	1.020	10.95	1.0

The above values are at a barometric pressure of 760 mm. of mercury and a humidity for the Carcel and Vernon-Harcourt standards of 10.0 liters of water per cubic meter of dry air. The humidity for the Hefner unit is 8.8 liters of water to one cubic meter of dry air.

Carcel Lamp. The Carcel lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

Pentane Lamp. This is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard, known also as the Vernon-Harcourt lamp, is not extensively used.

Amyl Acetate Lamp. This lamp, known also as the "Hefner lamp", is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gages furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusel oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure but it excels all other standards in that it is quite readily reproduced.

Table XXIV gives the value of the candle-power units of different laboratories in terms of the unit of the Bureau of Standards and also the values of the units of the Carcel and Vernon-Harcourt in terms of the Hefner, as accepted by the International Photometric Commission.

Working Standards. *Incandescent Lamp.* The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about 200 hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

PHOTOMETERS

Basic Principle of Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a "Bunsen screen" mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disk of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check the readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle on a photometer with a 300-centimeter bar. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares and holds true only when the dimensions of the light sources are small compared with the distance between them and when there are no reflecting surfaces present, as when the readings are taken in a dark room.

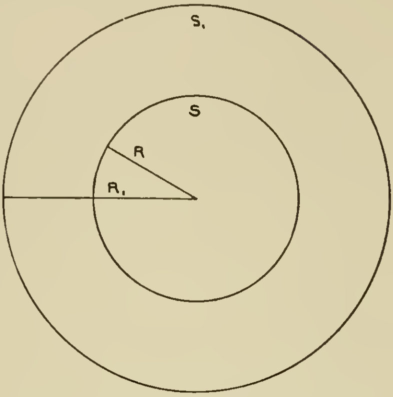


Fig. 83. Proof Diagram of the Law of Inverse Squares by Method of Concentric Spheres

The proof that the light varies inversely with the square of the distance from the source is as follows:

Consider two spherical surfaces, Fig. 83, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

Area of $S = 4\pi R^2$ sq. ft. (R is in feet.)

Area of $S_1 = 4\pi R_1^2$ sq. ft.

Let Q equal total quantity of light and q and q_1 equal light falling on unit surface of the spheres S and S_1 respectively. Then

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R_1^2}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R_1^2}$$

$$= 4\pi R_1^2 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R_1^2}{R^2}$$

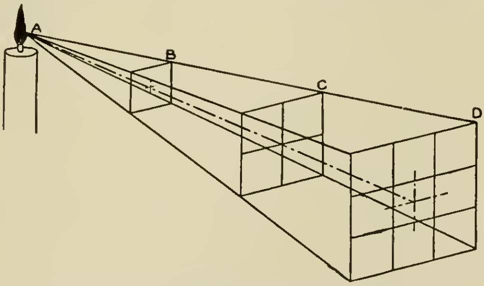


Fig. 84. Proof Diagram of the Law of Inverse Squares by Method of Screen Shadow

Fig. 84 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B, which is distant one unit.

Lummer-Brodhun Photometer. In addition to the Bunsen screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 85 the screen *S* is an opaque screen which reflects the light falling upon it from *L*, to the mirror *M*, when it is again reflected to the pair of glass prisms *A*, *B*. The surfaces are ground to fit perfectly at *s r* and any light falling on this surface will pass through the prisms. Light falling on the surface *a r* or *b s* will be reflected as shown by the arrows. We see then that the light from *L*, which falls on *a r* and *b s*, is reflected to the eyepiece or telescope *T*, while that falling on *s r* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms *A*, *B*. The rays falling on the surface *s r* pass through to the telescope *T*, while the rays falling on *a r* and *b s* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disk of light produced by the screen L_1, surrounded by an annular ring of light produced by *L*. When the illumination on the two sides of the screen

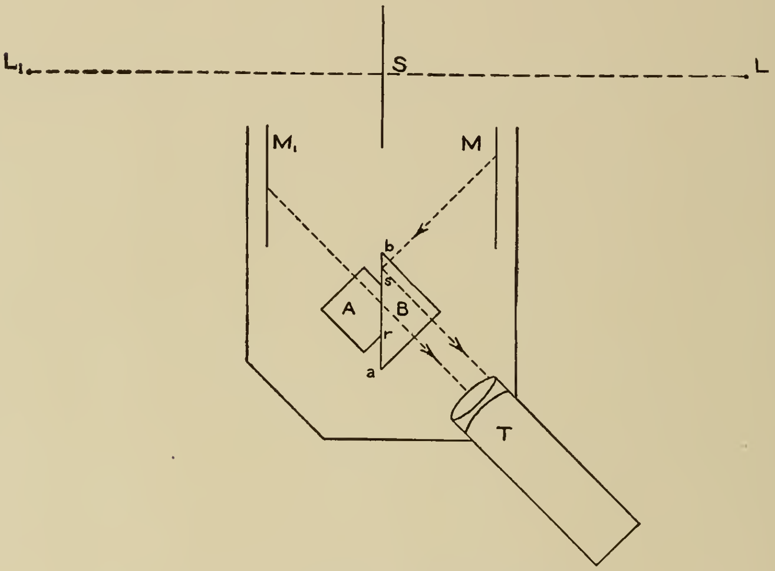


Fig. 85. Diagram of Lummer-Brodhun Screen

is the same, the disk and ring appear alike and the dividing circle disappears.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings

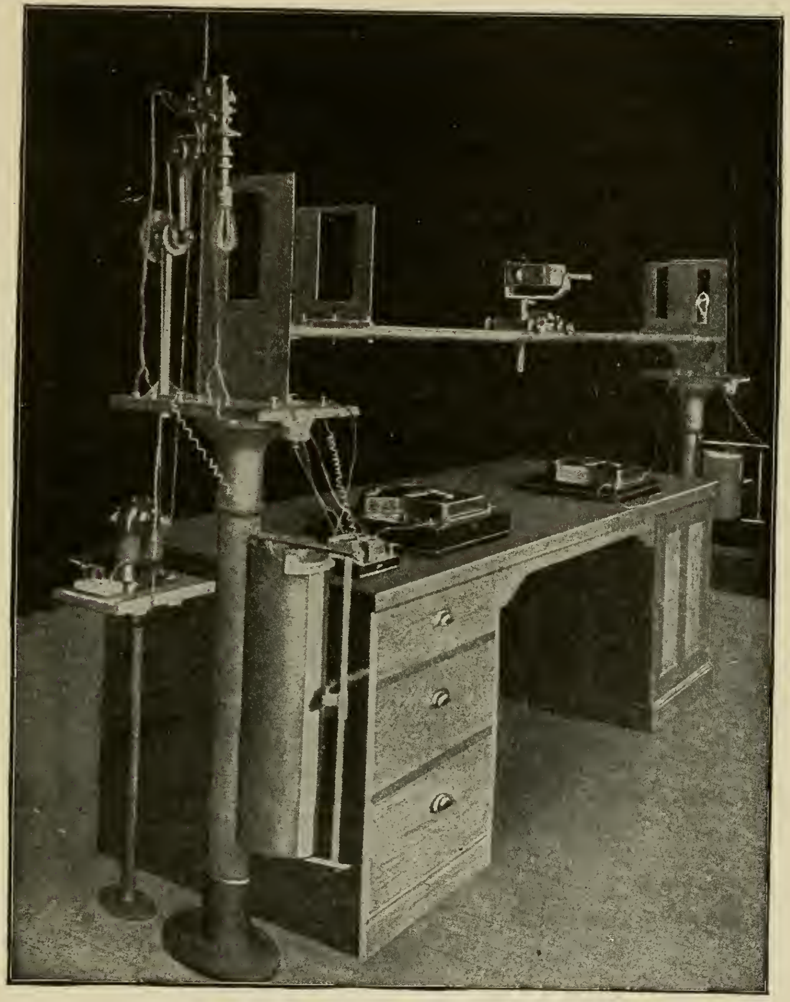


Fig. 86. Complete Photometer with Lummer-Brodhun Screen

serving as the true reading. This form of screen is used when especially accurate comparisons are required.

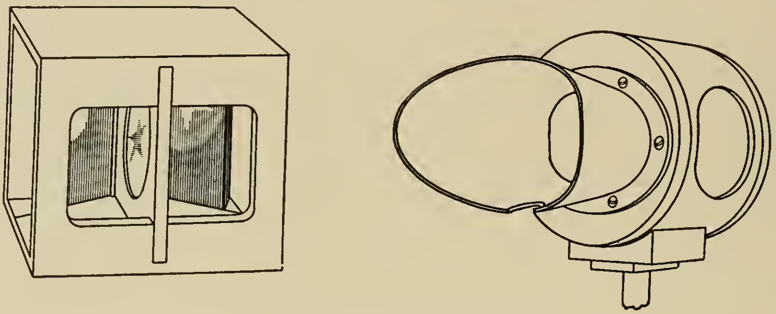


Fig. 87. Bunsen Screen and Sight Box

Fig. 86 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 87 shows a Bunsen screen and sight box. In Fig. 86, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen. If the lights are properly screened, photometric measurements may be made in rooms having light-colored walls.

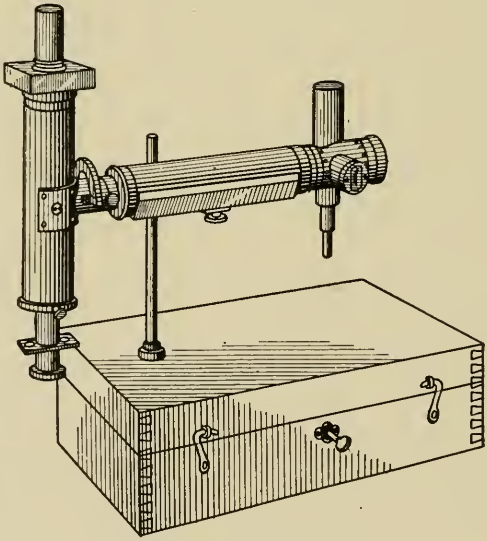
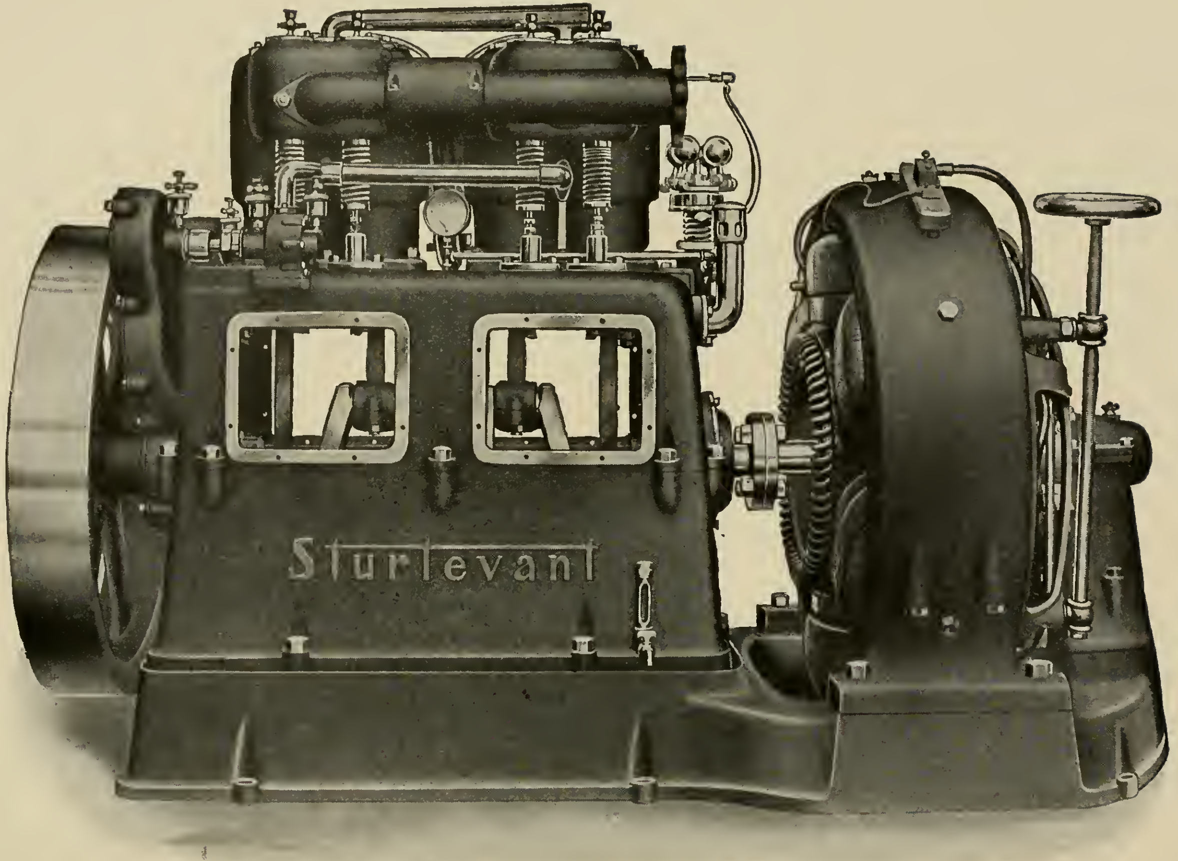


Fig. 88. Weber Portable Photometer



TEN-KILOWATT GASOLINE-ELECTRIC GENERATING SET WITH DOORS REMOVED SHOWING CRANKSHAFT
Courtesy of B. F. Sturtevant Company

Weber Photometer. As an example of a good portable type, the Weber photometer is shown in Fig. 88. This photometer is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

This apparatus consists of a tube *A*, Fig. 89, which is mounted horizontally and contains a circular opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube *A* is mounted the tube *B* which contains an eyepiece at *O*, a Lummer-Brodhun contrast prism at *p*, and a support for opal or colored glass plates at *g*.

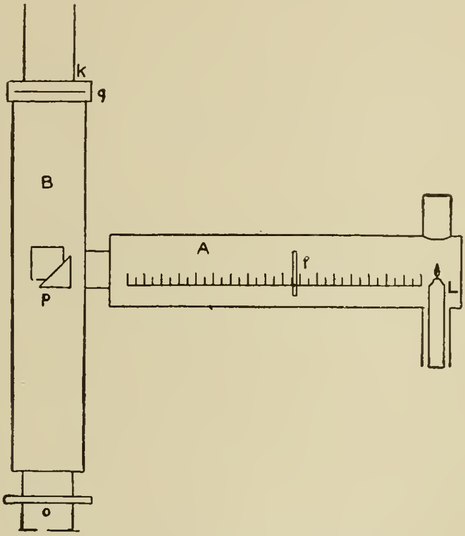


Fig. 89. Diagram of Weber Photometer

Operation. The tube *B* is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant *C*, when we have the formula

$$I' = C\frac{L^2}{l^2}$$

C corresponds to a particular plate at *g*; *l* is distance of screen *f* from the benzine lamp; and *L* is distance from the screen *g* to the light source being measured. Screens of different densities may be used at *g* depending on the strength of the light source.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *g*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

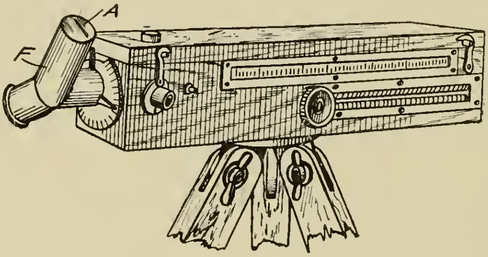


Fig. 90. Sharp-Millar Photometer

Portable Photometers. There is a large variety of portable photometers available which give more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of other instruments on the market is the "Universal photometer," more commonly known as the "Sharp-Millar photometer" from the names of its inventors. Views of this instrument are shown in Figs. 90 and 91. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at *B*, and consists of a special form of Lummer-Brodhun optical screen. A standardized incandescent lamp *C* is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens *G*. The instrument scale is calibrated in foot candles and in candle-powers.

When illumination is to be measured, a specially selected translucent screen is placed at *A* and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at *H*. A second plate *K* is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of *A* and *K* the same. When the intensity of a light source is to be determined, the screen at *A* is replaced by a small aperture and a diffusing surface *I* is put in place of the mirror *H*. The illumination of *I* is now compared with the illumination of *K*, and when the two are made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed and, as ordinarily equipped, the range in foot-candles is approximately from .004 to

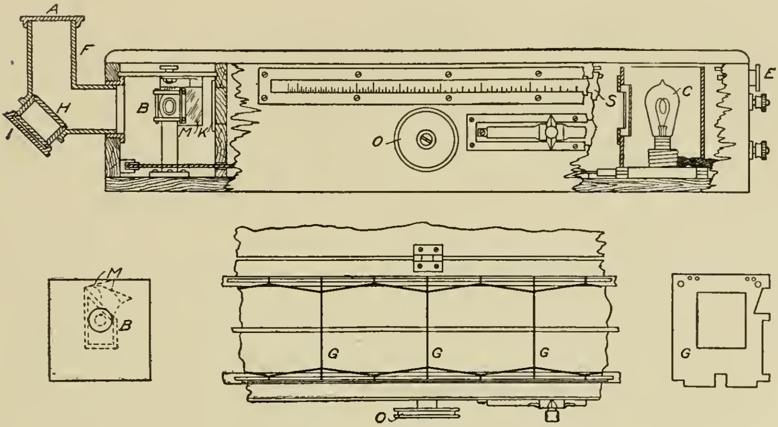


Fig. 91. Sectional View of Sharp-Millar Photometer

2000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, 24″×4½″×5″, and its weight, fully equipped, of 8 pounds. Considering its compactness, this photometer is capable of great accuracy.

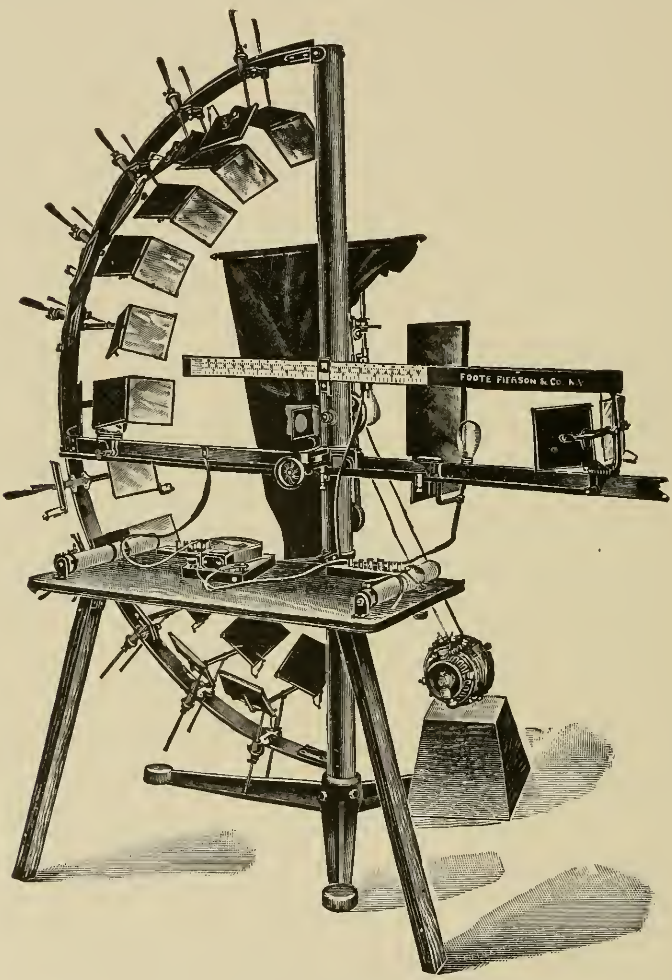

FOOTE PIERSON & CO. N.Y.

Fig. 92. Matthews Integrating Photometer

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be obtained from Fig. 92. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Another type of integrating photometer is known as the "integrating sphere" or globe photometer. If a light source is placed within a sphere the interior walls of which are coated with a white diffusing surface the illumination of that surface at any point is due partly to the light falling on it directly, and partly to the light reflected from the remainder of the surface of the sphere. The reflected light is proportional to the total flux of light from the light source and so, if the direct light is screened from the point considered, its illumination is proportional to the total flux of light, and hence to the mean spherical candle-power of the light source.

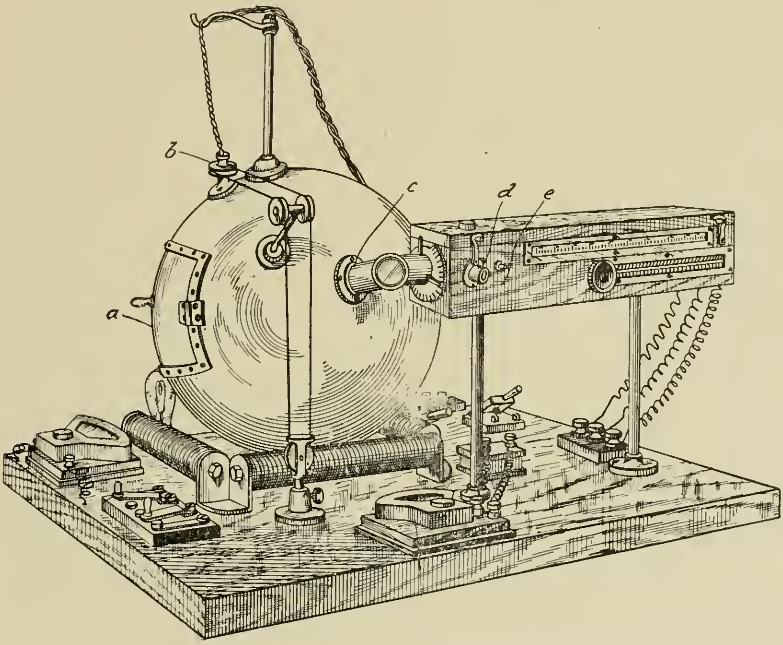


Fig. 93. Eighteen-Inch Integrating Sphere Equipped with Photometer

The practical application of this principle is so to arrange our properly coated sphere that the lamp to be tested may be readily inserted; to replace a small portion of the sphere by a piece of unpolished white glass; to shut off the direct rays of the lamp to be measured from this glass surface; and so to mount a photometer screen and standard lamp that the illumination of the glass section can be measured. Under these conditions the illumination of the glass screen is proportional to the mean spherical candle-power of the lamp under test. A substitution method is used in practice. A standardized lamp of the general type of the one to be tested is mounted in the sphere and the constant of the instrument for this type of lamp is determined. The unknown lamps are then put in place and their candle-power is readily determined, once the constant of the instrument is known. Figs. 93 and 94 give some views of the integrating sphere and indicate the range of the sizes in which it may be constructed.

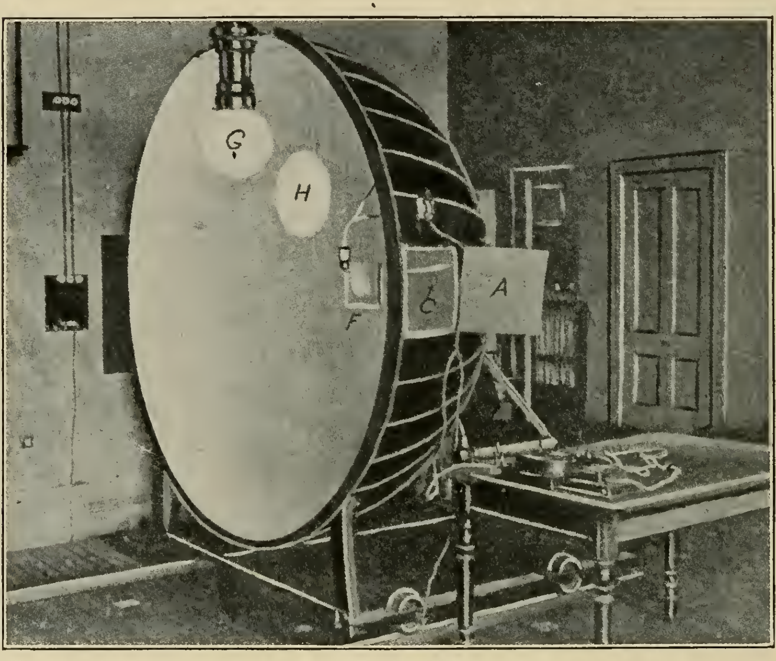


Fig. 94. Interior of 80-Inch Integrating Sphere

INCANDESCENT LAMP PHOTOMETRY

Apparatus. Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 95 shows one form of station photometer manufactured by Queen and Company. The controlling rheostats and shielding curtains are not shown here. Fig. 96 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale.* This scale is based on the law of inverse squares and reads the inverse

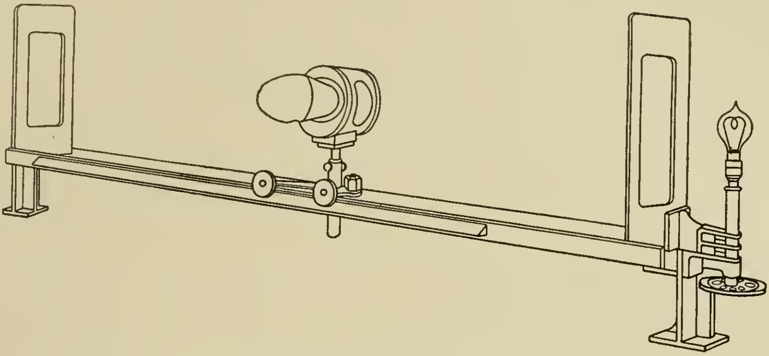


Fig. 95. Station Photometer

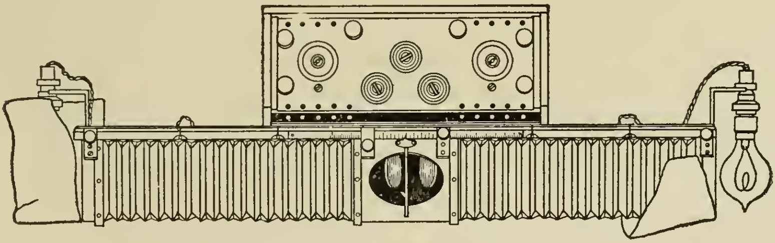


Fig. 96. Portable Photometer for Incandescent Lamps

ratio of the squares of the distances from the two lights being compared. If the standard used always has the same value, the scale may be made to read in candle-powers directly.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position. Lamps giving a uniform horizontal distribution curve need not be rotated.

For distribution curves a universal lamp holder, which will allow the lamp to be placed in any position and which indicates this position, is used.

For mean spherical candle-power the following method is used when the Matthews or integrating-sphere photometer is not available:

Measurement of the Spherical Intensity. For convenience, the tip of the lamp and its base may be termed the north and south poles, respectively. The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The mean of 13 readings taken at intervals of 30° is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30° and the last reading checking the first.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values
The mean of four measurements at the north pole of the lamp	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°	16
Twelve measurements 30° apart at the equator	12
Four null values at the south pole of the lamp	1
Total number of effective measurements	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles.

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90° and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

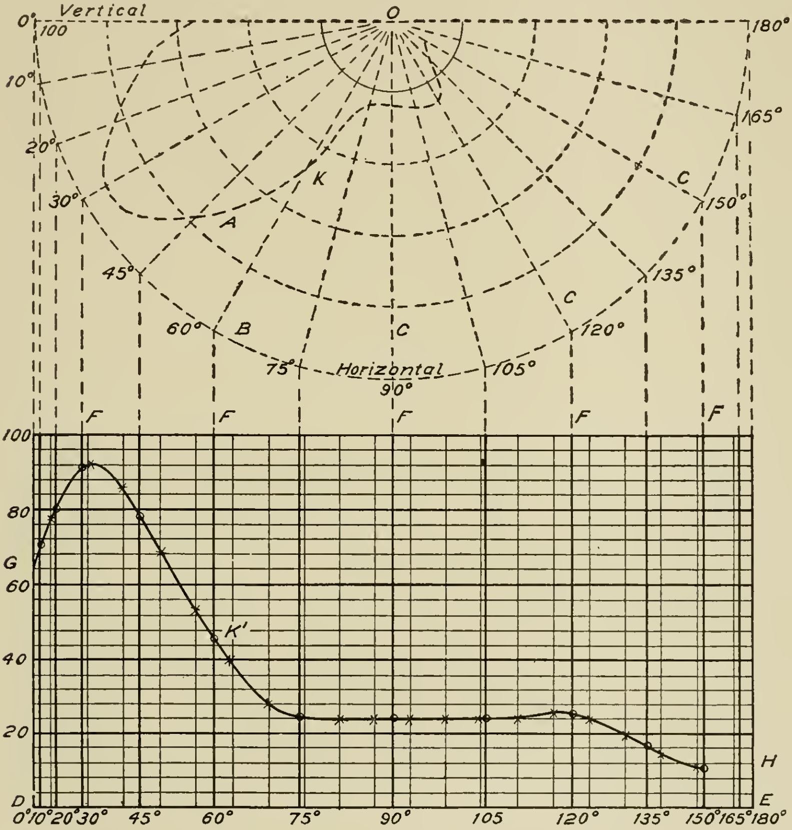


Fig. 97. Rousseau Diagram for Gem Lamp with Bowl Reflector

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

Rousseau Diagram. The Rousseau diagram may be used for determining the mean spherical candle-power of a lamp when its vertical distribution curve is known. Fig. 97 shows such a diagram made up for a gem lamp with a bowl reflector. Where the horizontal distribution curve of the lamp is not uniform, the values for the vertical distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale *A* and a circle *B* is drawn with the source of light *O* as a center. Radii *C* are drawn at equal angles about the light source and extended until they intersect the circle *B*. The points of intersection of these lines with the circle are projected upon the straight line *D E*. Distances from this line are laid off on the verticals *F* equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line *D E* and a curve drawn through the points just determined, *G H*, divided by the base line, is equal to the mean spherical candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divide by the corresponding base.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps, a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

ARC LIGHT PHOTOMETRY

Method Used. Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 26 and 27 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

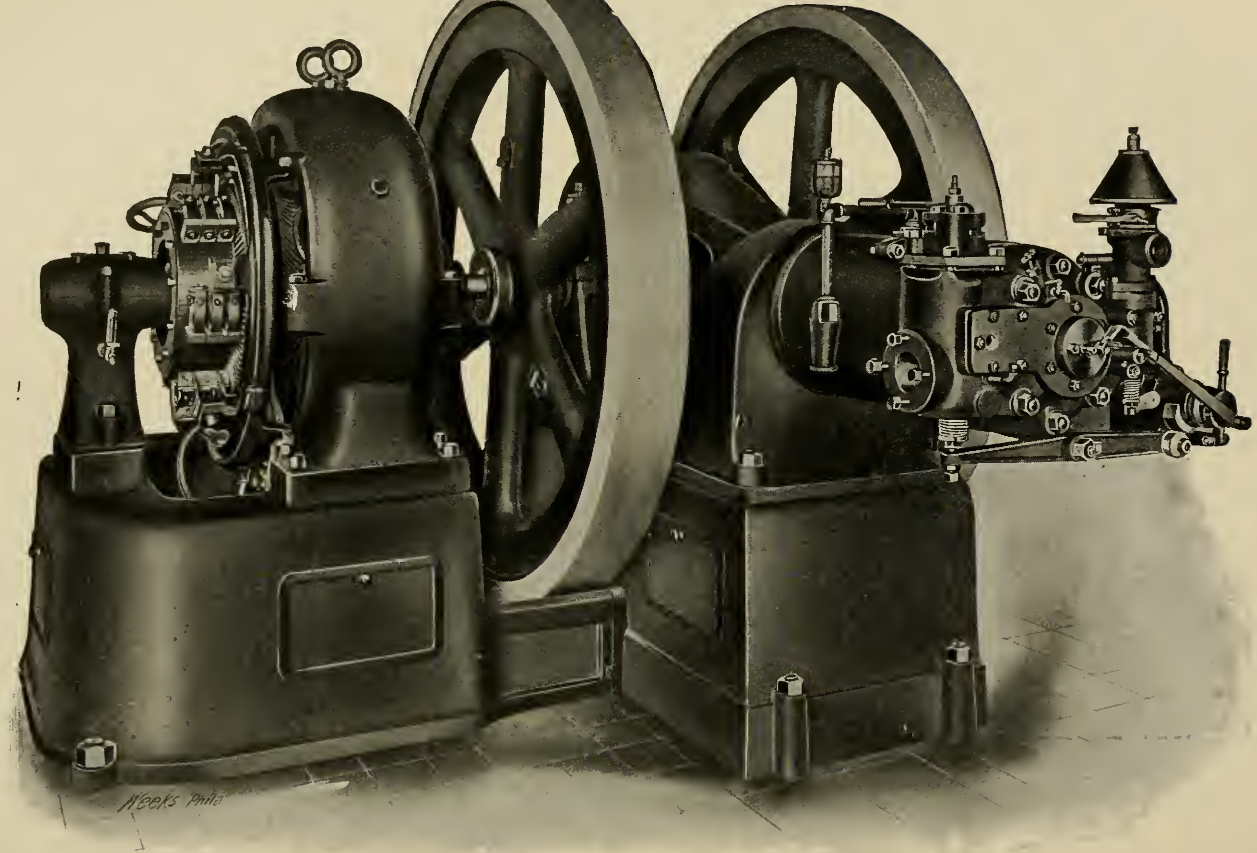
A special form of the Matthews photometer is also used for testing arc lamps.

Illuminometer. For the comparison of the illumination from arc lamps as installed in service, an instrument known as an "illuminometer" is sometimes used. This consists of a light wooden box, readily portable, having a black interior and arranged with two openings. One of these openings is for the purpose of admitting light, from the source being considered, to a printed card. The other opening is for the purpose of viewing this card, when illuminated by the light source. The printing on the card is made up from type of different sizes and the smallest size which is legible, together with the distance from the light source, is noted. Another method of application is to select some definite size of type and then to move the instrument from the light source to a point where this type is just legible and note the distance. From similar measurements taken on different lamps a good comparison may be obtained. Such an instrument is very convenient to use and results, obtained by different observers, check very closely.

Flicker Photometer. The flicker photometer is used for the comparison of different colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen and, *vice versa,* any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material having a diffusing surface and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eyepiece of the instrument and, during the other part of the revolution, a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers, it is found that results with different colored lights can be obtained which are comparable with results obtained with lights of the same color.



DIRECT-CONNECTED GAS-ENGINE-DRIVEN ELECTRIC LIGHTING SET
Courtesy of Otto Gas Engine Works

ISOLATED LIGHTING PLANTS

IN FARMING AND SCATTERED SUBURBAN DISTRICTS

With all its superlative merits, electric illumination has always possessed one supreme shortcoming—that of being available only in localities where consumers are numerous and closely grouped. Large farms and country estates occasionally made use of small electric power plants, driven by moderate sized steam and internal combustion engines of conventional types, or, in rarely favored locations, by waterpower, and while extremely cheap power, as at Niagara Falls, sometimes allows an uncommon extension of the economical distribution radius, such applications are genuinely successful only where they serve sufficient numbers of individuals to constitute virtually small urban or suburban groupings. The fact remains, therefore, that satisfactory modern illumination is still denied to the great majority of civilized homes—to over 70 per cent of the dwellings in the United States, for example, according to data compiled from census figures.

Ordinary illuminating gas, the immediate predecessor and still the close competitor of electricity, lacks most of the advantages of the latter, while at the same time being subject to all the limitations of use that attach to the expensive distribution of a service from a central works or station. It carries with it, moreover, such an ever-present danger of asphyxiation that it is probable it would long since have yielded its field to electricity were it not for its use in cooking and heating.

Attempts have been made, of course, to do away with this cardinal drawback of the isolated home, and acetylene-gas and gasoline lighting plants have had widespread sale, despite the fact that both produce much soot and heat as well as light, require frequent and expert attention, are costly to buy and maintain, and constitute a dangerous fire and explosion hazard.

There are two possible ways of providing electric light in a given locality. One is to transmit it in from a distance; the other is to generate the electricity in the vicinity. As yet, electric transmission lines are rarely more than two hundred miles long, while the great majority of central stations do not reach even ten miles into contiguous territory. This leaves but one remaining possibility—the installation of private generating plants of small capacity, each plant to embody complete within itself the fundamental essentials of dynamo and engine, together with the incidental essentials of lubricating and regulating systems.

Casually considered, especially a few years ago, this would have seemed hopelessly impracticable and might very reasonably have been construed into a demand that every householder become a competent engineer. But the world moves and the development of the automobile, for example—not to mention many other features on the highway of mechanical progress—has gone far to prove that it is not so inconceivably difficult at that for the average individual to become considerable of an engineer.

Still more pertinent are other considerations. A very few years ago the 16-candlepower carbon incandescent lamp was the established standard of electrical illumination. This standard unit consumed 55 watts of electrical energy—the theoretical equivalent of more than one-fourteenth of a horsepower. Practically, though, because of various electrical and mechanical losses, one horsepower could not be expected to keep more than eight of these lamps running at full efficiency.

In this same period of electrical and mechanical engineering, one horsepower represented at the very least some hundreds of pounds of expensive, bulky, dirty, noisy, indifferently built, and highly unreliable machinery, requiring practically constant and very competent attention to keep it in operation and in order.

But it is a fundamental scientific truth that mechanical progress never halts and that its triumphs more often come by processes of evolution rather than by sheer invention. Wherefore, in the improvement of the incandescent lamp and in the perfecting of the internal combustion motor, there begin to appear two seemingly distinct but actually related improvements converging towards a new result.

For on the one hand there has come the tungsten lamp and on the other the automobile and motorcycle engine. Paralleling each other in their development, the first, in its standard size, now consumes only 25 watts of current to emit 20 candlepower of light—a total, with present efficiencies of converting mechanical into electrical energy, of not less than 425 candlepower per horsepower, against no more than 125 candlepower per horsepower with the old carbon lamp. In the meantime, by the refinement of machine design and progress in methods of manufacture, one horsepower has come to signify a light, inexpensive, compact, clean, silent, excellently made, high speed, and highly reliable mechanism, capable of running for weeks upon end with a minimum of wear and only the most occasional inspection.

ELECTRICAL CONVENIENCES ON THE FARM

In suburban districts and in the country, therefore, there is a large field for small isolated plants, made possible by the small gas engine and low voltage electric lamp. The idea of utilizing the electric current was prompted by the coming of the cross-country trolley. Men within easy reach of these found it easy to get their supply, and those outside the zone, enlightened by this example, soon began making their own electricity by means of dynamos driven by gasoline engines or waterpower.

The price of small isolated plants has now been brought within reach of all, and the convenience of electric power is shown to be appreciated by the fact that great numbers of such plants are rapidly being installed.

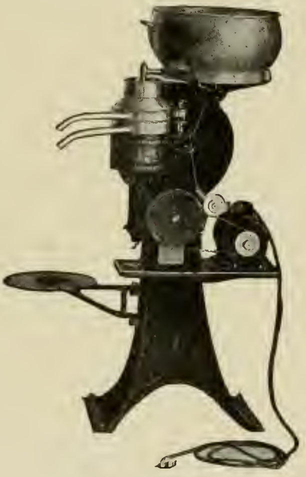


Fig. 1. Running DeLaval Cream Separator by Motor
Courtesy of General Electric Company

Applications. Within the last ten years three big companies manufacturing electrical apparatus have been catering almost exclusively to this trade. Churning is done with a little motor which also comes in handy for running a cream separator, Fig. 1, a sewing machine, or a washing machine. An excellent motor-driven pneumatic system is shown in Fig. 2. The 1-horsepower motor drives a "Typhoon" force pump with air-intake attachment, electropneumatic controller for starting and stopping the motor at certain pressures, and a pneumatic tank with a capacity of 350 gallons. Most all of the small operations and the necessary repair work about the farm, Fig. 3, can be done more quickly and better with power service than if done by hand. The feed grinder, Fig. 4, root cutter, fodder cutter, planing mill, circular saw, kindling wood splitter, corn sheller, small drill press, horse clipper, and hay loader, can all be operated by small motors. Incubators, Fig. 5, and brooders prove successful stepmothers to the little chickens and when electrically heated are far more reliable than when heated by a lamp. Milking machines operated by a motor are also more or less successful. By the aid of one of these, several cows can be milked while one cow is being milked by hand. Luxuries such as the electric flatiron, small electric stoves, and vacuum cleaners operated by electric motors, can be used when desired. In fact the uses of electricity on the farm are almost too numerous to list.

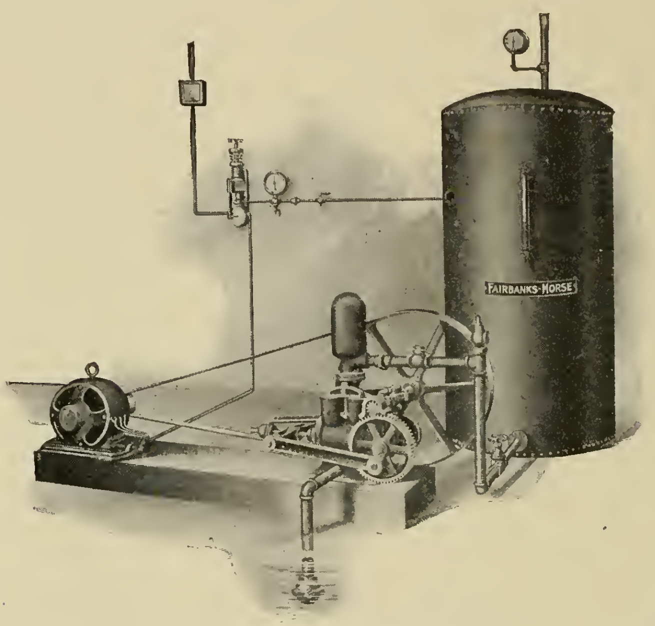


Fig. 2. Fairbanks-Morse Pneumatic Water System
Courtesy of Fairbanks, Morse & Company

Portable Power Plant. One of the latest outfits is intended to run the machines used in the fields. The machinery is simply a motor mounted on a truck on the model of the old portable farm engine. The truck is hauled about from place to place and is made ready for operation by connecting with the farm power plant. The wires are easily led from point to point wherever power or light is

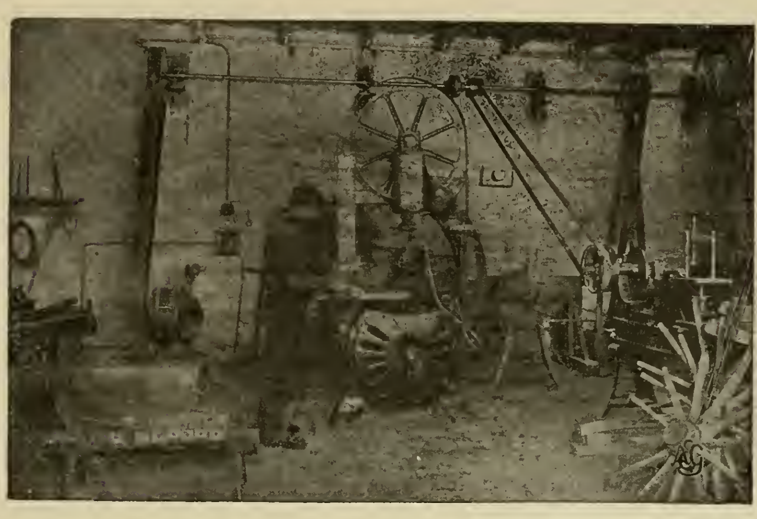


Fig. 3. Typical Motor-Driven Farm Machine Shop
Courtesy of General Electric Company

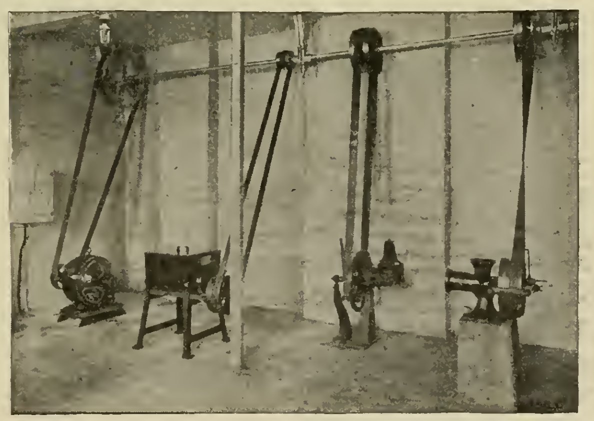


Fig. 4. Motor Driving Grinding Machines Through Line of Shafting
Courtesy of General Electric Company

required, Fig. 6. Thus it is possible to thresh in the open field by means of electric power and to operate other apparatus. This class of motor has passed beyond the experimental stage. It is as simple to operate as a pump.

Choice of Power. The cheapest generating stations are those where it is possible to use water from a running stream. A little dam, holding back sufficient water to make the power, furnishes an easy solution of this question. Where there is no water or where it is of insufficient volume, any of the popular styles of engines may be used.

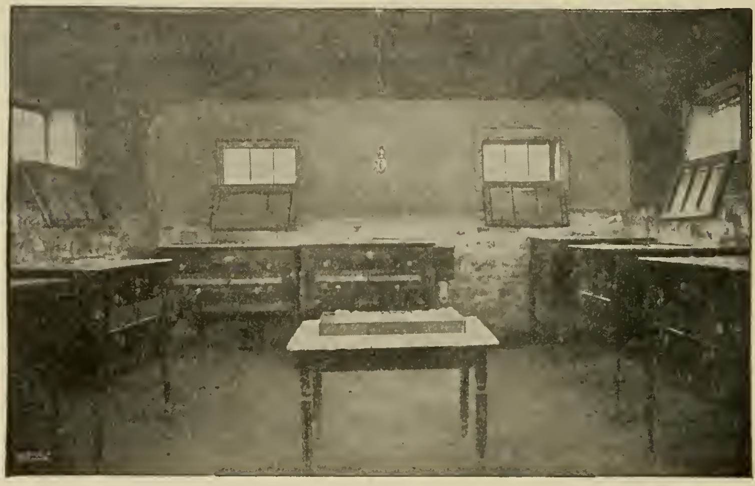


Fig. 5. Electrically-Heated Incubators
Courtesy of General Electric Company

The windmill, the standby of the farmer, is expected later to popularize electricity on the farm, for while the amount of power furnished by the ordinary mill is comparatively small, it is sufficient to develop lighting and small power requirements. On account of the fact that the windmill is useful only when there is a wind, it is necessary to utilize storage batteries. The cost of these, as well as of maintaining them, is rather large but is being steadily decreased.

Refrigeration Plant. A refrigerating equipment for the farm should be highly appreciated. An electrically-operated refrigerating plant has the advantage of constant temperature, dryness, and cleanliness as well as cheapness. Again, most of the power for refrigerating would be required in the summer, the time of the year when the least amount of artificial light is required, so it would not necessitate any extra engine capacity. Different compartments are arranged so that the temperatures best suited to the contents can be maintained for each product.

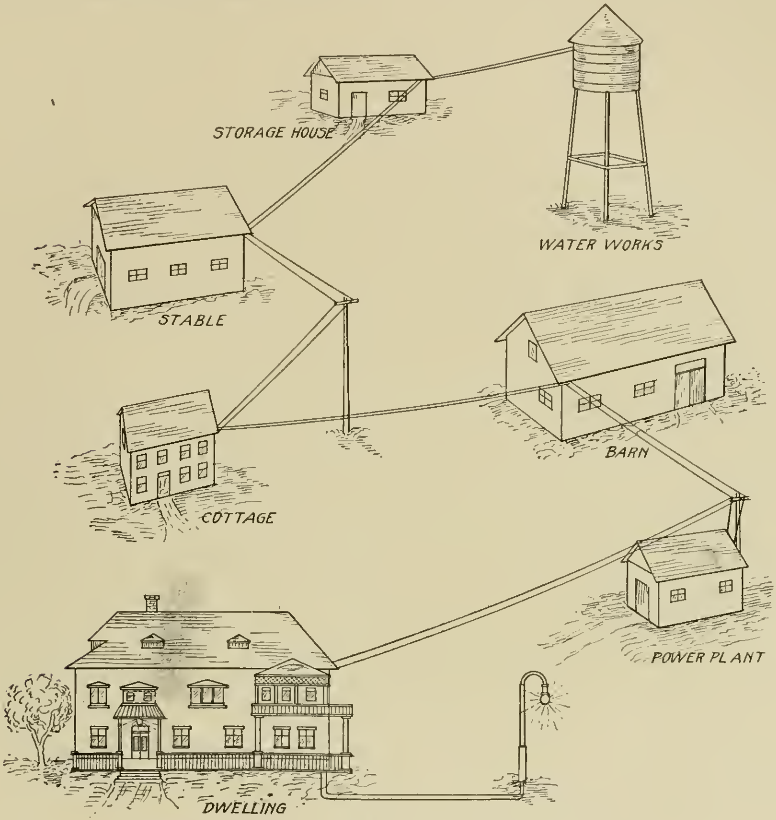


Fig. 6. Typical Wiring Diagram for Farm Electric Plant

THE SMALL PLANT

Equipment. The small plant should comprise a dynamo driven by a gasoline engine and a storage battery, Fig. 7. The dynamo may be run during the day or at any convenient time to charge the storage batteries. When the battery is fully charged, the engine can be disconnected and if desired used for other purposes, and during the evening the lighting current can be furnished by the batteries. As the carbon filament lamps require so much power to operate, it is advisable to use the tungsten lamp, in which case the engine and dynamo need only be about one-third as large. In using the tungsten lamp, there is also the advantage of operating on low voltages, ordinarily a 30-volt system being used for small plants. The special advantage of this is in the lower cost of the storage batteries. If 2-volt batteries are used, only 15 or 16 cells will be required to make the necessary 30 volts.

Cost. To arrive at the cost of such a plant, assume the case of a house requiring about 40 lamps to light it completely. In the average cases for lighting, we will assume one hour per day for each lamp connected. In such a house 40 lamp hours would be used each day. It would be advisable to install a storage battery of 80 lamp hours in such case, in order that the lamps may be run for 2 days and thus avoid running the engine every day. This will require an engine of about 3 horsepower, costing about $125. The required dynamo will cost about $100 and the battery about $110. A switchboard will be necessary, costing about $75. This outfit will amount to $425 and the wiring, lamps, fixtures, and extra labor will cost in the vicinity of $150 more, making a total expense of about $575. A space 10 feet by 16 feet will be found sufficient in which to install the apparatus and it would be wise to install the plant in a

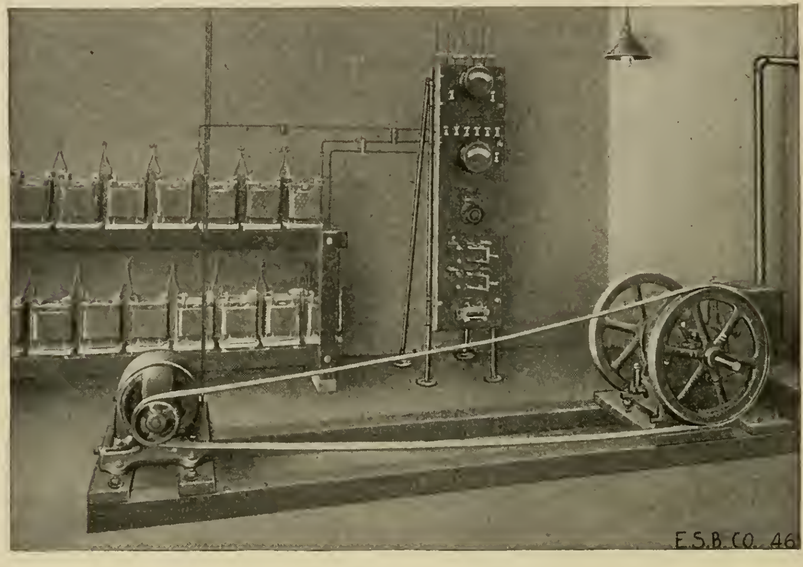


Fig. 7. Belt-Driven Generator with Storage Battery Auxiliary
Courtesy of Electric Storage Battery Company

small separate building. Such a plant as the above should give good service with little attention and at a comparatively small cost. The 3-horsepower engine running at full load for about 5 or 6 hours will fully charge the battery and at a cost of about 6 cents per hour for fuel, making the average cost for each lamp about one-third of a cent. This compares very favorably with the cost of electric house lighting in the large cities.

A 10-horsepower plant is a little less costly in proportion than a 3-horsepower outfit. The power plant and wiring for even a large farm can be installed for less than $1000.

If a waterfall is available, the expense of operation can, of course, be cut considerably. After the water wheel is once installed there is very little expense for maintenance and repairs. Arrangements can be made to control the operation of the plant from the house, so that little attention need be given the plant, probably one visit a week being sufficient. Electric lighting adds greatly to the attractiveness of a house and reduces the fire risk and is, therefore, bound to occupy a large place in the future development of farm industry.

Wiring the House. In wiring a house and arranging the fixtures, it is always best to select and locate the fixtures first and do the wiring afterwards, although the reverse is usually done and with poorer results. In order to give a good practical illustration, we will take as an example a house which has, on the first floor, 4 rooms with a front and back hall; on the second floor, 5 rooms and a hall. The cellar may have several small rooms divided off.

In the dining room, 2 fixtures with bowl reflectors will give a good effect when hung at a height of about 6 feet from the floor. If frosted tip lamps are used, the light will be sufficiently distributed to give a pleasing effect. The living room should be well lighted, a 3-light fixture in the center of the room being usually sufficient. This should be hung about 6½ feet from the floor. If a concentrated light is desired, a table lamp will do and may be connected to one of the sockets of the fixture. One lamp about 8 feet from the floor will give sufficient illumination for the hall. One light will also be sufficient for the kitchen, but it should be hung on an adjustable bracket about 6 feet from the floor and preferably between the stove and table. One lamp can be placed on the ceiling of the front porch, just in front of the door. In each bedroom, one light on a bracket fixture placed directly over the dresser will give a good effect. With the lamp inclined at about 45 degrees, a good direct illumination for the room will also be obtained. If there are closets in the bedrooms a drop light in each will be helpful. In such case care should be taken never to hang the lamp on the hooks or where it would come in contact with clothing. In the upper hall and bathroom, single hanging light fixtures about 7½ feet from the floor with frosted lamps will give all the light necessary. The lights in the cellar should be on the ceiling in order to give a good distribution and should have reflectors above them.

POWER HOUSE

Design and Equipment. A good idea for a power house to hold a small isolated plant is to have a concrete structure set in the ground, the top being flush with the surface of the ground. The cables connecting the power plant with the house can be laid underground in conduits and in this way the plant and wires do not disturb the beauty of the estate—if this is taken into consideration—and it is being done more and more so each year. The space in the power house can be divided into three parts, the largest being for the engine and generator as one unit. Beyond the engine in the corner is the cooling tank, and to the right the switchboard. With the concrete floor and white walls and ceilings, such a plant makes a very presentable appearance. In the next room is the storage battery, containing an upper and lower set of cells arranged in rows with two aisles between. By having the ceiling and walls double, the acid fumes cannot escape except through the window, which should face away from the house. The third room is used for a storage room for tools, supplies, etc. A 4-inch iron pipe should rise to the roof to allow for the escape of the exhaust. Another pipe can lead to the gasoline storage tank, which should be about 30 feet distant.

STANDARD PLANT

An entire lighting plant that can be installed in a space 12 feet long and 3 feet wide is furnished by one of the large manufacturing companies. The only limitation as to location of such a plant is that it must be kept clean and dry within a reasonable distance of the point where most of the lights are used, and preferably where the battery may be ventilated to the outside air. A dry basement, stable, or garage may be conveniently used for the location of this plant.

Power. The power is furnished by a simple economical close-regulating gasoline engine. This drives the dynamo, which may be used to run the lights direct or which may store up electricity in a storage battery for use in the early morning hours or at other times when it is not convenient to run the engine for the small amount of light desired.

Equipment. The standard equipment comprises everything necessary for the complete installation of the plant, except the wire, and this may easily be obtained anywhere at a moderate price. The outfit has a shipping weight of approximately 2200 pounds and consists of the following:

1 2-horsepower engine, using gasoline, kerosene, or low grade distillate oils
1 50-light, 32-volt, compound-wound dynamo
1 Endless dynamo belt
1 Slate panel switchboard and all instruments necessary for operating
1 Storage battery, capacity 13 lights for 4¾ hours
Fixtures and shades for 50 lights
50 15-watt Mazda tungsten lamps

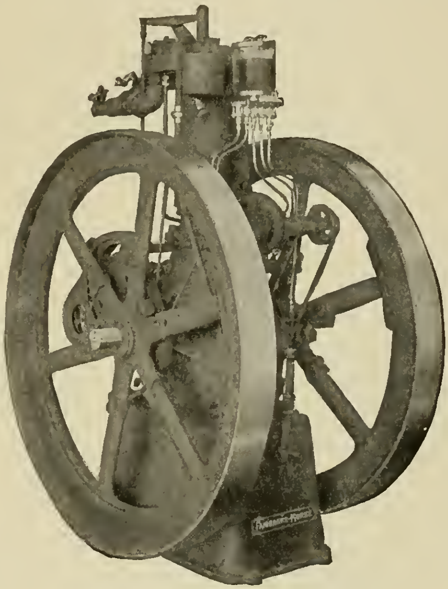


Fig. 8. Four-Cycle Gasoline Engine
Courtesy of Fairbanks, Morse & Company

Engine. The engine, Fig. 8, is especially designed and constructed for this kind of service. It is of the 4-cycle type with throttling governor, extra heavy flywheels and bearings, and an efficient lubricating system which permits of its operating for long periods with little attention. Its regulation is exceptionally close as required for electric lighting service. The special governor permits a direct driving of the standard dynamo without resorting to heavy balance wheels such as are necessary with ordinary power engines that are sometimes offered for this purpose. The engine is handsomely finished, mounted upon a substantial iron base, and the excellent workmanship employed in its construction shows its reliability and durability for years of continuous efficient service.

Dynamo. The dynamo, Fig. 9, is a compound-wound, multipolar, self-regulating machine having a capacity of 25 amperes at 32 volts. It is heavily and durably built like the engine, the aim being to produce a machine that will not merely give its rated capacity for a temporary period but will continue to give efficient service for years without causing the expense and inconvenience that would be incidental to cheap and light construction. It gives a steady brilliant light and regulates automatically, producing only the amount of electricity required, whether its entire capacity or only a single light may be burning, thus saving the consumption of fuel when running only at part load. The current generated is of low voltage and is entirely harmless, so that any unpleasant results from accidental contact with uninsulated parts of the machine are avoided.

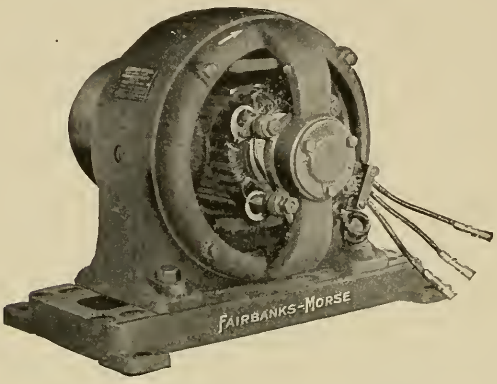


Fig. 9. 32-Volt Compound-Wound Generator
Courtesy of Fairbanks, Morse & Company

The belt is a single endless leather dynamo belt of suitable length to provide for the installation of the engine and dynamo with a distance of about 8 feet between the centers of their shafts.

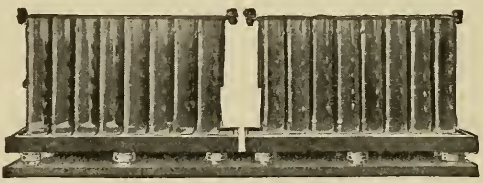


Fig. 10. Storage Battery Unit of 16 Exide Cells
Courtesy of Fairbanks, Morse & Company

Storage Battery. The storage battery, Fig. 10, consists of 16 cells, the elements being assembled in glass jars. The jars are mounted upon wood or glass trays, containing a small quantity of sand which provides a soft bedding and holds them firmly without danger of breakage. The battery, when fully charged, will furnish enough electricity to run 9 lights for 7½ hours, 13 lights for 4¾ hours, 18 lights for 3¾ hours, or 30 lights for 2 hours, after which service it must be recharged as promptly as possible, but, if not completely discharged, immediate recharging is not necessary. When fully discharged, it requires about 10 hours to completely recharge it. Under ordinary conditions of service, most of the lighting being done direct from the dynamo, the battery need be completely recharged only once or twice a week. The complete battery equipment consists of the following parts:

16 "Chloride Accumulator" elements, with glass jars and glass covers
2 Extra glass jars
2 Extra glass covers
2 Eight-cell wood sand trays (shelves or brackets not included)
4 Bolt connectors
12 Insulators
4 Inches of lead tape
⅛ Bushel of sand
1 Hydrometer
2 Socket wrenches
Necessary electrolyte

Switchboard: The switchboard, Fig. 11, is a marine finish slate slab, mounted upon angle iron supports and provided with wall braces which hold it at a suitable distance from the wall. On the face of the panel are mounted the following instruments:

1 Voltmeter, which indicates when the dynamo is running at the proper voltage
1 Ammeter, that indicates the load on the machine and approximately the number of lights burning
1 Double-pole double-throw main line switch with fuses
2 Double-pole double-throw battery switches
1 Rheostat for adjusting the voltage of the dynamo
2 Pilot lamps with battery charging resistance
12 Voltmeter receptacles
1 Four-point voltmeter plug
1 Underload circuit breaker

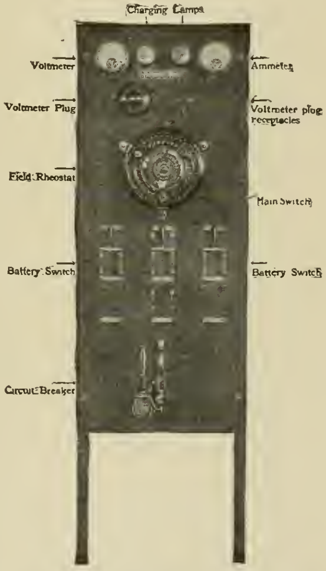


Fig. 11. Switchboard for Lighting Plant
Courtesy of Fairbanks, Morse & Company

On the back of the board there are mounted two sets of resistance coils which control the current for charging the battery; also all the necessary connections between the instruments and switches are made on the back of the board, while on the front of the board are mounted the switches, rheostat, and other instruments.

The lights are run from the dynamo by throwing the main line switch up, with both battery switches open. The battery is charged by throwing the two battery switches upward and closing circuit breaker. The lights may be run at the same time or not, as desired. The lights are run from the battery by throwing all switches downward. The pilot lamps indicate when the battery is receiving its proper charging current, and the voltmeter plug, with its receptacles, permits of properly adjusting the dynamo voltage and inspecting the condition of charge of the battery.

Lamps. The lamps should be tungstens. The clear white light emitted by these lamps is the nearest approach to sunlight of any artificial illumination that has yet been invented. Each lamp consumes 15 watts and gives 12 candlepower of a clear white light that is equal in illuminating value to the ordinary 16-candlepower carbon light. These lamps are very nearly as durable and strong as carbon lamps and will give an average life of 1000 hours when operated at their normal voltage. They are regularly furnished with a clear bulb, but a frosted bulb may be had, if desired, at a small extra charge.

Fixtures and Shades. The fixtures are of simple design, each being fitted with Edison key sockets and with shade holders—16 fixtures are furnished having sockets for 28 lights, and the rest of the sockets are mounted on flexible drop cords with ceiling rosettes. The drop cords are completely wired and for installation have simply to be screwed to the ceiling and connected to the lighting wires. The single light fixtures are all completely wired and may be installed in the same simple manner. The fixtures having more than one light have each individual arm wired complete and wires furnished for the main stem. They are assembled by simply screwing the arms into the body casting and then soldering the arm wires to the two wires passing through the stem, which makes it a very simple operation. A 4-light fixture may be assembled in a very few moments. The standard outfit comprises the following fixtures:

2	Four-light chandeliers, with shades	8 lights
2	Three-light chandeliers, with shades	6 lights
2	Two-light chandeliers, with shades	4 lights
6	One-light pendants, with shades	6 lights
4	One-light wall brackets, with shades	4 lights
	Total	28 lights
22	Five-foot drop cords, with shades	22 lights
	Total	50 lights

Shades are provided for each fixture. The 4-, 3-, and 2-light fixtures are equipped with white shades, while the 1-light pendants and wall brackets are of frosted glass.

Operation. The plant requires little care. Thousands of gasoline engines are in use on farms and in stores and small manufacturing establishments where they do not receive skilled attention and their reliability is fully proved.

This special engine is designed with reference to its operation with the least possible attention and about all that it requires are fuel, lubricating oil, and a spark for ignition. It will operate continuously and steadily without further attention, requiring, in fact, less care than an ordinary kitchen stove. The dynamo is entirely automatic in its operation and generally runs better by being left alone. Fill the jars with distilled water once a week and do not allow the battery to stand in a low state of charge.

The following instructions for connecting up a low voltage lighting plant, such as the above, with the switchboard, will be found of value:

The right-hand wire coming through the dynamo frame is positive; the left-hand wire is negative; the middle wire is the field wire.

The dark brown plate of the battery (with buttons) is positive; the gray plate (with perforated screen) is negative.

Mount the dynamo rheostat on the front of the board and attach the wire that runs from the positive pole of the dynamo switch to one of the terminals.

Looking at the back of the switchboard, connect the right-hand, or positive, wire from the dynamo to the right-hand upper terminal of the dynamo switch; connect the left-hand, or negative, wire to the left-hand upper terminal of the dynamo switch. Run the field wire up the back of the board and through the hole in the panel to the other terminal of the rheostat.

Connect the positive plate of one-half of the battery to the right-hand middle terminal of one battery switch and the negative plate of the same half to the left-hand middle terminal; and connect the second half of the battery to the other battery switch in the same way.

Connect the lamps to the right-hand middle terminal of the dynamo switch and to the left-hand upper terminal of the left-hand battery switch.

Mount voltmeter on front of board and attach wires to the little screws on ammeter shunt, finding the proper direction by test after starting the dynamo.

Put the ampere fuses in the top and bottom of the dynamo switch.

To test the polarity of any low voltage dynamo, battery, or circuit, put the terminal wires in a glass of water, holding them carefully not less than one inch apart to avoid short circuit, and add a little salt or a few drops of electrolyte from the battery to the water. Bubbles of gas will arise from the negative pole.

THE LARGE PLANT

Location. *In General.* For large isolated plants the problem usually presenting itself is a peculiar one. Instead of the interior space for the equipment determining the dimensions of the plant, it is the dimensions that are fixed and any available rooms are used for the plant and planned accordingly. The engines and generators, of course, take up the majority of the space and are best arranged in one large room. The boiler room is usually separate and contains the pumps and bins for coal and ashes. The illustration, Fig. 12, is of a direct-connected engine and generator—a very compact

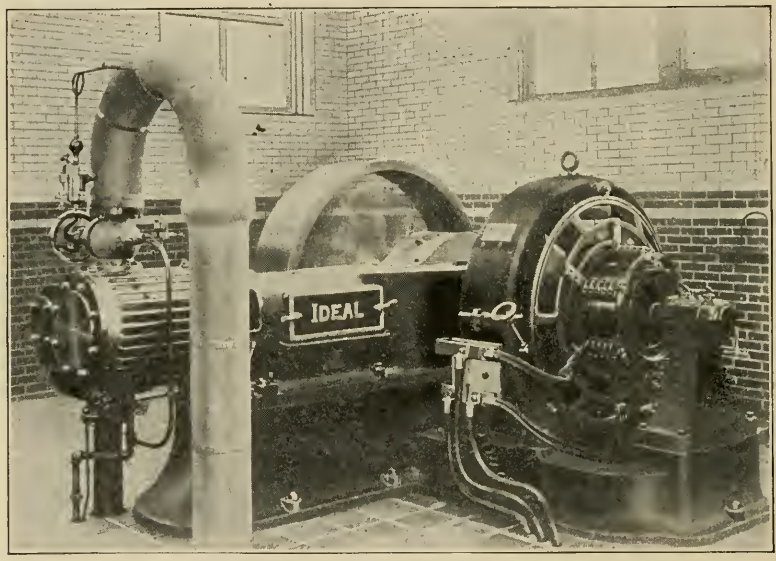


Fig. 12. Direct-Connected Generator Unit for Hotels and Apartment Buildings
Courtesy of A. L. Ide & Sons

unit. Sufficient allowance should be made for the future increase of load in the size of the engines, boilers, and countershaft.

Generators. It is not necessary when adding new generators as they are required, to have them parallel with the machine already installed. They may be put in in any position where they will not take up too much space. It is also very convenient to have a storeroom to be used as a place for various supplies, tools, and appliances that will be needed in the operation of the station. These may be kept under lock and key in order to prevent daily waste and loss resulting from carelessness.

Prime Mover. The relative positions of the boilers, engine, and generators in a plant of this kind should always be arranged so that the steam piping connecting the boilers and engines does not pass over the generators or over any of the apparatus in the station that would be seriously affected by water occasionally dripping from the pipes. The generators should be located so there is sufficient space between them to allow for cleaning and repairing. They should not be placed close to windows or other openings where rain might come through, as it is very important that they be kept as dry as possible.

Switchboard. The switchboard should be mounted against the wall near the door leading from the engine room into the boiler room. The advantages of a switchboard located in this way are that the operator can obtain an unobstructed view of each individual machine and in consequence has a much better control over all of them. Furthermore, while engaged at work on the engines and generators, he can see the measuring instruments on the switchboard and get a fairly good approximate reading. In case of emergency, it is sometimes necessary for the engineer in charge to be as nearly as possible in several places at the same time in order to avoid an accident. By locating closely together all controlling devices and having no moving belts or pulleys between them, the possibility of accident will be greatly decreased.

Engine Speed. In lighting plants where electricity is used, the speed of the engine has a decided effect upon the cost of the electric generator. The higher the steam consumption of the engine, the larger the boiler plant required to furnish steam. The cost of the steam piping is also increased with an engine consuming relatively large amounts of steam. In order to fix upon the cheapest unit for a particular case, it is necessary to consider the following elements:

(1) The first cost of the engine,
(2) The cost of foundations,
(3) The cost of building,
(4) The cost of space or buildings required to house the engine,
(5) The efficiency of the engine,
(6) The cost of boilers,
(7) The cost of coal per ton,
(8) The cost of maintenance and repairs.

If all of these elements are considered and the total fixed cost involved in the selection of a particular type is carefully estimated, and to this is added the capitalized operating cost including fuel, oil, repairs, etc., it will be frequently found that the engine of lower efficiency will produce cheaper power than the engine of higher efficiency, and this is particularly true where the cost of fuel is low.

Engine Type. No arbitrary rules can be laid down to determine the choice of the proper type of engine. Each particular installation requires individual study. The point to be emphasized is that investment efficiency rather than steam efficiency is the prime consideration. The selection and setting of the boilers, the design of the steam piping, the utilization of the waste gases, are all equally as important as the installation of the engine. It is here that the engineer assumes the responsibility for efficiency. The engines as a rule are designed by the builders for given capacities and can usually be relied upon to fulfill their guarantees.

Where steam heating is required, electric power may be generated as a by-product of the heating plant at a cost of less than 2 cents per kilowatt-hour in the majority of cases. The isolated plant with exhaust steam heating must be considered as a separate problem because of the wide variation in load, cost of coal, water, labor, and amount of exhaust steam heating.

Comparison with Big Central Station. An interesting question and one which often arises is why the central station in which maximum economy is obtained by cutting down all losses, generating in large units, operating condensing, etc., cannot generate power at a far less cost than the isolated plant with its small capacity and efficiency. The answer to this is that the central station can produce power *at its own switchboard* for a cost, including both operating and fixed charges, of one cent per kilowatt-hour, but this is only a part of the total cost to the consumer, since it is necessary to have an elaborate and expensive transmission and distributing system of copper cable, feeder, sub-station, etc., in order to deliver the power. The power house furnishes electricity to the distributing system, which acts as a carrier and which must pay interest, depreciation, franchise, and maintenance charges, just as must a railroad, and as with a railroad there is a natural tendency towards rate discrimination, so it is the favored customer who obtains power at a reasonable charge while the other man bears the burden.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT-CURRENT MOTORS

---

1. State briefly the fundamental principle of the motor.

2. What is meant by the *torque* of a motor? How is it related to the power? If the field and armature current are constant, how is the torque related to the speed?

3. If the output of a motor is 60 horse-power, and the armature makes 490 revolutions per minute, what is the torque?

4. If the pulley of the motor in the preceding question is 22 inches in diameter, what is the effective pull upon the belt?

5. What is the commercial efficiency of a 500-volt motor which takes 120 amperes and delivers 71.6 horse-power?

6. What is meant by the counter-electromotive force of a motor? What relation does it bear to the efficiency?

7. The current in the armature of a shunt motor is 50 amperes; and the E.M.F. at the brushes, 240 volts. If the armature resistance is 0.38 ohm, what is the counter-E.M.F.?

8. Upon what does the speed of a motor depend?

9. Explain briefly the different methods used to vary the speed of shunt motors.

10. What disadvantages are there in controlling the speed of a shunt motor by a rheostat in the armature circuit?

11. A 230-volt shunt motor takes 55 amperes at full load, the speed being 760 revolutions per minute. What resistance must be inserted into the armature circuit to give half the full-load torque at two-thirds speed? How many watts are lost in this resistance under these conditions?

12. A shunt generator is to be used as a motor. What changes are necessary? Should the brushes be shifted, and, if so, to what point?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY

PART I

---

1. What items are to be considered in selecting a machine?

2. What means are applied for connecting the engine, or other prime movers, with the generator?

3. State the formula for determining the approximate width of a single belt required to transmit a given horsepower.

4. What are the advantages of rope driving?

5. What is the usual speed of shafting employed in textile mills?

6. Give diagram for connecting shunt type of direct-current generator.

7. Explain how to run two compound-wound generators in parallel.

8. What is the chief difference in appearance of a synchronous converter as compared with a direct-current generator?

9. Considering a six-phase rotary converter, the alternating current across phases 1 and 2 is 1000 volts. What is the direct current?

10. Give wiring connection for two direct-current generators on a three-wire system.

11. How is the speed control of a shunt motor obtained?

12. What is a differentially-wound motor?

13. Considering a three-phase generator Y connected, what is the value of the line current in comparison with the current per phase?

14. How is the direction of rotation of induction motors reversed?

15. Give the characteristics of repulsion induction motors.

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY

PART II

1. How can the friction of the bearings and brushes be roughly tested?

2. Which is the most accurate way to determine the temperature rise in electrical apparatus?

3. How is the balance tested on small and medium-sized machines?

4. What is the safe-carrying capacity of #5 B & S rubber insulated copper wire?

5. Make a sketch of an enclosed fuse.

6. Describe the fall-of-potential method for locating faults.

7. Describe the voltmeter test for insulation resistance.

8. For what reasons are water-box resistances used?

9. What is a tachometer?

10. Calculate the torque of a machine, the horsepower of which equals 50 and its speed is 550 revolutions per minute at full load.

11. According to what formula can the mechanical power of a generator or motor be calculated?

12. Give an expression for the efficiency of a generator and for the efficiency of a motor.

13. In which cases are instrument transformers employed.

14. Which is the most common trouble encountered with dynamo-electric machinery?

15. To what is the humming noise in an alternator due?

16. What are the general causes for a motor to stop or to fail to start?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

---

1. Into what different types are electric lamps usually divided?
2. Define the term *efficiency of an incandescent lamp.*
3. Give a short description of the preparation of the filament in incandescent lamps.
4. Describe the nitrogen-filled type of incandescent lamp.
5. What shows the distribution curve of a lamp?
6. What are the advantages of the quartz mercury-vapor lamp?
7. Explain the principles of the electric arc.
8. Draw a sketch of the series mechanism for direct-current arc lamps.
9. Enumerate the different types of arc lamps.
10. What is the voltage required of a direct-current arc open type?
11. Make diagram of connections for luminous arc lamp.
12. How may the systems of power distribution be divided in connection with electric lamps?
13. Draw a diagram of an anti-parallel feeding system.
14. Define *illumination.*
15. What is the *unit of illumination* and its *value?*
16. What is understood by *intrinsic brightness?*
17. What is the relative reflecting power of yellow wall paper?
18. Calculate the approximate illumination at the center of a plane 3 feet above the floor in a room 18 feet square and 12 feet high, the room to be lighted by four 16 candle-power lamps placed one at the center of each side wall 10 feet above the floor; the coefficient of reflection of the wall to be taken as 60 per cent.

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